THE MEASUREMENT OF INSPECTOR ACCURACY

By

LEE ALLEN WEAVER

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
1972

ACKNOWLEDGMENTS

The writer would like to thank Dr. Warren Menke for his assistance and guidance in the preparation of this dissertation. He would also like to thank the other members of his committee.

TABLE OF CONTENTS

		Page
ACKNOWLEDGMENTS		ii
LIST OF TABLES		v
LIST OF FIGURES		xi
KEY TO ABBREVIATIONS		xii
ABSTRACT		xv
CHAPTER I	INTRODUCTION	1
II	A SURVEY OF THE LITERATURE	4
III	MEASURES OF INSPECTOR ACCURACY	18
IV	EXPECTED VALUES FOR THE SAMPLING DISTRIBUTION OF THE RATIO OF DEFECTIVE PRODUCT REJECTED	30
V	CALCULATION OF EXPECTED VALUES	46
VI	VERIFICATION OF DERIVED EXPECTED VALUES BY SIMULATION	62
VII	SINGLE HYPOTHESIS SAMPLING PLANS FOR INSPECTION ACCURACY	73
VIII	DOUBLE HYPOTHESIS SAMPLING PLANS FOR INSPECTION ACCURACY	94
IX	CONCLUSION	114

TABLE OF CONTENTS (CONTINUED)

	Page
APPENDIX	117
REFERENCES	128
BIOGRAPHICAL SKETCH	131

LIST OF TABLES

TABLE		Page
2.1	INSPECTOR ACCURACY IN THE USE OF PRECISION INSTRUMENTS	13
2.2	DEFECTS FOUND IN FOUR SUCCESSIVE VISUAL AND GAGING INSPECTIONS OF 30,000 UNITS. . . .	15
3.1	SUMMARY OF ACCURACY MEASURES OBTAINED FROM TWO SETS OF SAMPLE DATA	29
4.1	SUMMARY OF EXPECTED VALUE FUNCTIONS	39
5.1	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.05.	50
5.2	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.10.	51
5.3	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.25.	52
5.4	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.01.	54

LIST OF TABLES (CONTINUED)

TABLE		Page
5.5	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.05	55
5.6	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.10. . . .	57
5.7	EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.25.	59
6.1	RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 1, NUMBER INSPECTED = 1000, NUMBER AUDITED = 500.	68
6.2	RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 2, NUMBER INSPECTED = 1000, NUMBER AUDITED = 500	
6.3	RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 1, NUMBER INSPECTED = 1000, NUMBER AUDITED = 200.	70
6.4	RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 2, NUMBER INSPECTED = 1000, NUMBER AUDITED = 200.	71
7.1	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 250	78
7.2	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 100	79

LIST OF TABLES (CONTINUED)

TABLE		Page
7.3	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 50.	80
7.4	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 10.	81
7.5	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 500	82
7.6	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 200	83
7.7	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 100	84
7.8	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 20.	85
7.9	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 2500.	86
7.10	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 1000.	87

LIST OF TABLES (CONTINUED)

TABLE		Page
7.11	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 500	88
7.12	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 100	89
7.13	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 10000, AUDIT SAMPLE SIZE = 5000.	90
7.14	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 10000, AUDIT SAMPLE SIZE = 2000.	91
7.15	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 10000, AUDIT SAMPLE SIZE = 1000.	92
7.16	MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 10000, AUDIT SAMPLE SIZE = 200	93
8.1	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.50, INSPECTION SAMPLE SIZE = 100	99
8.2	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.50, INSPECTION SAMPLE SIZE = 500.	100

LIST OF TABLES (CONTINUED)

TABLE		Page
8.3	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.50, INSPECTION SAMPLE SIZE = 1000.	101
8.4	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.50, INSPECTION SAMPLE SIZE - 5000	102
8.5	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.50, INSPECTION SAMPLE SIZE = 10000	103
8.6	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.60, INSPECTION SAMPLE SIZE = 100.	104
8.7	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.60, INSPECTION SAMPLE SIZE = 500.	105
8.8	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.60, INSPECTION SAMPLE SIZE = 1000.	106
8.9	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.60, INSPECTION SAMPLE SIZE = 5000	107
8.10	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.60, INSPECTION SAMPLE SIZE = 10000	108

LIST OF TABLES (CONTINUED)

TABLE		Page
8.11	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.75, INSPECTION SAMPLE SIZE = 100.	109
8.12	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.75, INSPECTION SAMPLE SIZE = 500.	110
8.13	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.75, INSPECTION SAMPLE SIZE = 1000	111
8.14	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.75, INSPECTION SAMPLE SIZE = 5000	112
8.15	AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY = 0.90 AND ACCEPT ACCURACY = 0.75, INSPECTION SAMPLE SIZE = 10000.	113

LIST OF FIGURES

Figure		Page
4.1	Sample Production Flow for Case 1 with No Replacement, Audit Accuracy = 100 Percent	42
4.2	Sample Production Flow for Case 2 with No Replacement, Audit Accuracy = Inspection Accuracy.	43
4.3	Sample Production Flow for Case 1 with Replacement, Audit Accuracy = 100 Percent	44
4.4	Sample Production Flow for Case 2 with Replacement, Audit Accuracy.	45
6.1	Histogram of Simulation Results	66
7.1	Graphical Presentation of a Single Hypothesis Statistical Test for Inspection Accuracy.	74
8.1	Graphical Presentation of a Double Hypothesis Test for Inspection Accuracy.	95

KEY TO ABBREVIATIONS

ACI A measure of inspection accuracy based on the ratio of correct inspection.

ADR A measure of inspection accuracy based on the ratio of defective product rejected.

AGA A measure of inspection accuracy based on the ratio of good product accepted.

API A measure of inspection accuracy based on the reduction in the defect rate resulting from inspection.

AU A measure of inspection accuracy based on utility theory.

D The absolute number of defectives produced by manufacturing (DGI + DDI)

DDI Number of actual defective items observed to be defective by the inspector while performing an initial inspection.

DGI Number of actual defective items observed to be good by the inspector while performing an initial inspection.

DI The number of items observed by the inspector to be defective while performing an initial inspection (GDI + DDI).

DR The number of items observed to be defective by the auditor while performing a reinspection.

DR* The absolute number of defectives in a reinspection sample.

GDI Number of actual good items observed to be defective by the inspector while performing an initial inspection.

GGI Number of actual good items observed to be good by the inspector while performing an initial inspection.

GI The number of items observed by the inspector to be good while performing an initial inspection (GGI + DGI).

GR The number of items observed to be good by the auditor while performing a reinspection.

IOQL The inspection outgoing quality level is the ratio of good product in the production line after initial inspection but prior to reinspection by an auditor.

MQL The manufacturing quality level is the ratio of good product in the production line prior to inspection.

NI The inspection sample size during an initial inspection.

NR The number of items reinspected by the auditor.

OQL The outgoing quality level is the ratio of good product that is shipped to the customer after all inspections have been performed.

PI A population parameter of the fraction defective found by the inspector during an initial inspection.

PR A population parameter representing the fraction defective found by the auditor while performing a reinspection.

V(DDI) Value to the company of inspection determining an actual defective item to be defective.

V(DGI) Value to the company of inspection determining an actual defective item to be good.

V(GDI) Value to the company of inspection determining an actual good item to be defective.

V(GGI) Value to the company of inspection determining an actual good item to be good.

Abstract of Dissertation Presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

THE MEASUREMENT OF INSPECTOR ACCURACY

By

Lee Allen Weaver

December, 1972

Chairman: Warren Menke
Major Department: Management

The purpose of this study is to derive methods of determining inspector accuracy during the production process.

The inspection function is viewed as the action taken by an inspector in his role as a decision maker. This basic function consists of examining a product and then deciding whether or not it conforms to the specification. Since it is imperative that defective material not be shipped to the customer, it is necessary to be concerned with inspector accuracy.

A search of the literature has revealed that very few studies involving inspector accuracy have been published; however, there may be studies on file in many industrial inspection departments. Those studies that have been published involve, for the most part, controlled experimental conditions which attempt to determine causes of inspector inaccuracy and are not concerned with a quantitative measure of inspector accuracy. A survey of the literature is included to show the need for quantitative measures of inspector accuracy that are obtained during the production process.

The dissertation discusses five possible measures of inspector accuracy: the ratio of correct inspection, a utility theory approach, the ratio of good product accepted, the ratio of defective product rejected, and the accuracy of product improvement. The advantages and disadvantages of each measure are reviewed. Sample calculations for each measure are included based on two sets of data obtained from the literature.

Based on current methods of data collection by industrial inspection departments and their application in the studies found in the literature, the ratio of defective product rejected is further examined. The ratio of defective product rejected is determined by dividing the total number of defectives found by the inspector by the total number of defectives in the lot. During the actual production process the only way to determine the total number of defectives in the lot is by an audit reinspection of the lot to determine how many defectives were missed by the original inspector. Two cases are explored. In the first case the auditor is perfect and has an accuracy of 100 percent. In the second case the auditor has the same accuracy as the initial inspector.

For each case an accuracy function is derived, as well as the mean and standard deviation of the function.

Two types of sampling plans are derived. Single hypothesis plans determine whether an acceptable inspection

accuracy is not being met based on the number of defectives found during the audit inspection. Double hypothesis plans determine whether a preselected acceptable inspection accuracy level or a preselected unacceptable inspection accuracy level is being attained. The double sampling plans require that the audit sample size as well as the number of audit defectives be stated in the sampling plan.

An effective tool for determining inspector accuracy has been developed for use by industry. The sampling plans result in estimates of inspector accuracy which can be used to determine the actual manufacturing quality level and the actual outgoing quality level. Good estimates of the outgoing quality level are required to determine future warranty and customer liability costs.

Examples of the two types of sampling plans have been included in the dissertation. Computer programs have been included in the appendix which can be modified to meet any user's specific needs.

CHAPTER I

INTRODUCTION

The rise of consumerism, resulting in increased liability by the manufacturer, has caused control of the production process to become increasingly important. While in the past, manufacturing errors that would cause product malfunction often were not detected prior to consumer use, it is now imperative that these errors be detected before the product is shipped to the consumer. The detection of such defects is the responsibility of the quality inspector, and since no process is perfect, defects will occur.

The present approach taken by manufacturers is based upon the assumption of accurate inspection. This dependence will exist as long as the number of defective units produced is less than the allowable number of defective products permitted to reach the customer. It is obvious that the percentage of defective units will vary depending upon the product and the production process involved. During the past 15 years production facilities with which the author has been associated have had control charts that have indicated defect rates of from 5 percent to 70 percent for subassemblies. With these types of defect rates,

considerable reliance needs to be placed on the ability of the inspector to prevent them from being shipped to the customer. To determine "typical" perfect defective values would require a separate study in itself.

The above considerations lead us to a concern for inspector accuracy. A search of the literature reveals that few studies on inspector accuracy have been published, although there may be such studies in the files of inspection departments throughout the United States.

Results of studies that are published are taken from experiments performed under controlled conditions. A typical experiment involves taking a product with a known number of defects and submitting them to inspectors to determine how many defects they can find. No papers were found which gave specific procedures to measure the inspector's accuracy during the production process based on accept/reject decisions involving the product currently produced. Many journal articles and books on quality control do mention two possible methods, "salting" the assembly line with known defectives or using an audit inspector. Required sample sizes and the calculation of quantitative accuracy measures are left unanswered.

Top management will obtain information on the quality of their product without any special effort on their part. These data will include consumer complaints of defective products, financial data through the cost accounting system

concerning dollar losses of excess scrap and rework, and complaints from the manufacturing personnel concerning unreasonable rejections. Even if all this data is gathered together and organized, it is not sufficient to give management adequate control of quality problems. These data do not provide a measure of the quality of the final product as seen by the customer.

Companies have long recognized that financial performance cannot be measured effectively without a system of cost accounting. In a similar manner, companies will need to recognize that quality performance cannot be measured effectively without a system of quality accounting.

CHAPTER II

A SURVEY OF THE LITERATURE

The majority of the literature findings were based on investigations of causal factors under controlled experimental conditions. Management and production engineers need to know their relationship to job performance and ultimately need a method of measuring their own inspector's accuracy during the production process. A number of leading books on statistical quality control (18, 19, 20, 21, 27) do not even consider the effects of inspector accuracy when discussing the application of acceptance sampling plans.

Juran (9), as early as 1935, published evidence of inspector biases. He felt that the serious study of inspector accuracy should be the analysis of the occurrence of systematic, rather than random, errors. Inspectors, being human, do not behave randomly. Rather, when they make errors a pattern emerges. In his influential 1951 book, Juran (22) reproduced the same data and added rather picturesque names to two types of inspector bias, "censorship" and "flinching."

In censorship the inspector excludes unacceptable findings. For instance in an inspection plan, three was the maximum number of allowable defects. While accepting a lot was a simple matter, rejecting one involved a great deal of disliked paper work and trouble with the production people. As a result, the inspector censored his findings so that an unbelievably large number of lots "just happened" to have the maximum number of allowable defects. Very few of the lots contained four or more defects. A more Poisson-looking distribution would probably portray better the actual number of defects per lot.

Censorship also occurs when the inspector "finds" defects, rather than "ignores," them. Juran (22) gives an example where the sampling plan was to take a sample of 100; if no defects were found the lot was accepted, but if one or more defects were found an additional sample of 165 was taken. Since the time allowance for the second sample was so liberal, the inspector could increase his personal efficiency by finding sufficient defects to reject the first sample. Very few lots contained no defects precluding the taking of the second sample.

In flinching, the inspector accepts items which are only slightly outside acceptance limits. Juran (22) found two biases apparent from this study. The experiment consisted of asking the inspector to read a needle meter with digital numerals. The scale was from 0 to 50. First the

meter was graduated every two units, and the human tendency to read to the nearest graduated unit showed itself in the excessive number of even-numbered readings. Second, the flinching occurred at a meter reading of 30. Although no observations were recorded for 31, 32, or 33, it seems most reasonable that some product occurred there. In effect, the inspector had changed the acceptable maximum limit from 30 to 33. In several places Juran speaks of "honest inspecting" in contrast to inspection involving censorship or flinching. The implication is that these biases are deliberate and that the inspector is therefore being dishonest. This may be true, but a psychologist would be quick to point out that it need not be deliberate. The inspectors could be completely unaware of their biases and might be quite as shocked as anyone upon being shown what they had been doing. Juran recommends possible measures of accuracy which are discussed in the next chapter.

McKenzie (14) feels that the main causes of inspector inaccuracy fall into the following categories: basic individual abilities, environmental factors, the formal organization, and social relationships. He describes many situations which can lead to inspector inaccuracy for each of the categories.

The ultimate limit of inspector accuracy is his individual capability. The reading of instruments is dependent upon the eye. The checking of noise level is dependent on

pitch. Micrometer accuracy is dependent upon touch and the eye.

Environmental factors discussed by McKenzie include light, temperature, noise, and work position. Formal organization factors included training, ill-defined standards, repetitive boredom, and gauges and tools supplied. Social relationships included relationships with production personnel, inspection supervision and management.

McKenzie apparently ran controlled experiments in support of his conclusions; however, no data were presented. He points out that when the experiments were run, the inspectors knew they were run, and therefore the results did not represent their every-day rates.

McKenzie offers three solutions to the controlled experiment problem. One way is the introduction of known defectives, examples of which are given later in this chapter. Inspection supervision check on inspector accuracy is rejected since his job is not to check not the product but to supervise the inspection of them. An audit inspection performed by a separate organization is recommended as the best solution.

A recommendation that inspection accuracy should be a design consideration was found in two papers (3, 28). The argument is that proper operation of a piece of equipment is dependent upon defectives being detected by inspection.

Sampling techniques have been developed which can be used in quality system audits (12, 15). The auditing function is limited to determining adherence to policies, procedures, and instructions and not to hardware reinspection.

Schwartz (16) discusses a technique to determine whether an inspector has developed inconsistent biases by looking for non-random runs of accepted or rejected lots. His technique does not result in a measure of inspection accuracy.

The following paragraphs give the results of specific studies performed in the area of inspector accuracy. The results of most of the findings lead to causes of inspector inaccuracy and can all be assigned to one of McKenzie's groupings.

Jacobson (8) became concerned with quality control inspectors. Plant opinion was that these inspectors were 95 to 98 percent effective, partly because of the non-routine type of work they performed.

A unit was built with 1,000 soldered connections with 20 defects deliberately built in. Ten consisted of a wire wrapped around the terminal but not soldered. The other 10 were poorly soldered; they were so insecure or loose that the wire would move in the solder joint. Some 39 inspectors of "all grades" were given one and one-half hours to inspect the unit, the average inspection time on the regular inspection line. Jacobson reported as a result of his experiment that

the inspector accuracy was 82.8 percent. This data is further used in the next chapter in the derivation of possible accuracy measures.

In defense of the reasonableness of the task put to the inspectors, Jacobson cited two facts, that no defect was found by all inspectors and no defect was missed by a majority of the inspectors.

Jacobson investigated many aspects of his data. The average inspector identified 83 percent of the defects, four found 100 percent of the defects, while one found 45 percent. There were very sizable differences among the inspectors. Unfortunately, not even the four inspectors who found 100 percent of the defects had a perfect record. Two of them produced two defects each in finding the 20 defects, one erroneously found two extra defects, and the fourth found one extra defect and produced six defects himself.

It would seem that the insecure or loose connections would be more difficult to find than those in which the wire was simply wrapped around the terminal. This was not the case, however, at least not to any significant degree. The solderless connections were found 84 percent of the time, while the loose connections were found 82 percent of the time.

Jacobson found that age was not related to accuracy. The age of the inspectors varied from 18 to 59. There

was a slight relationship with visual acuity as measured by the Orthorater.

Hayes (7) reported on the inspection of piston rings for surface defects. The foundry defects consisted of sand and gas holes and about half of the rings produced were usually scrapped. Hayes took 40 defective rings, selected to cover the range of defects typically found. The rings were submitted to seven inspectors. Sixty-seven percent of the defective rings were correctly classified as such. Only 10 percent, four rings, were judged by all seven inspectors to be defective. Hayes also submitted the rings twice to the inspectors, getting 7(40) = 280 pairs of decisions. Of these 280 pairs of decisions, 23 percent were reversed.

In a second study, Hayes sent a lot of rejected rings back through inspection and found that 67 percent were then accepted. The inspectors were led to believe that the lot had been reworked, though never told so. After this poor showing, a second rejected lot was resubmitted. This time the inspectors were told that the lot had not been reworked, and 64 percent were correctly rejected. Of great interest in this is the tremendous effect of the attitudes held by the inspector; if he believes the product is good, he will miss a good many defects.

Tiffin and Rogers (17) studied the accuracy of tin plate inspectors. Some 150 inspectors judged 150 plates, of which 61 were defective. The defects were surface

blemishes, unevenness in the coating of tin, and heaviness or lightness of the coating. The inspectors were required to classify each plate as satisfactory or defective, and if defective, to identify the type of defect. The average inspector made 78.5 percent correct identifications. The 150 inspectors ranged from 55 to 96 percent. The four classes of defects were appearance defects I, II and III and defective weight of the tinning.

Accuracy scores were very little related to visual acuity, height, weight, age, or experience of the inspectors. For example, the correlations between amount of experience and accuracy in identifying each type of defect were -0.05, -0.07, 0.00 and 0.06. Contrary to the expectations of the supervisors in the department, the more experienced inspectors were not the better ones.

Ayers (1) studied 45 inspectors of rayon yarn cones. He does not report any accuracy values; however, he found very low correlations between accuracy and vision tests, age, amount of production, and job experience.

Marien (13), in the earliest study located, studied the introduction of a wage incentive system on the performance of inspectors. While primarily concerned with the incentive system, he notes that 1,700 tinned disks previously passed by inspection were given a reinspection by two general foremen and the chief inspector. Only 2 percent were found at all questionable, that is, with black spots the size of

pin points. Day-working inspectors were never known to have so high an accuracy. The incentive system was claimed to be the cause of the high inspection accuracy.

Lawsche and Tiffin (10) made a study of inspector accuracy in the use of precision instruments in two plants; one was a manufacturer of variable pitch propellers for aircraft and the other was a manufacturer of precision parts for aircraft and automobile engines. In all cases the true values were determined by ultra-precision instruments and Johansen blocks. Every inspector was well trained and was tested only on the instruments he used daily on his own job. The inspectors were given separate booths and were encouraged to take their time. It was suggested that they take five measurements and then record their best judgment as to the correct dimension. All instruments were properly calibrated.

Between 113 and 162 inspectors were studied, using a variety of precision instruments. Tolerances for each instrument, established by the engineering department, were identical with those encountered in the shops themselves. Table 2.1 summarizes the results.

Table 2.1 bears close inspection. From 9 to 64 percent of the inspectors could read within the tolerances expected of them. With Vernier micrometers, not even half of the inspectors could read within 0.0001, and accuracy decreased dramatically with the large 6-inch Vernier micrometer to

TABLE 2.1

INSPECTOR ACCURACY IN THE USE OF PRECISION INSTRUMENTS

Instrument	Number of inspectors	Established tolerance ±	Percentage of inspectors reading within tolerance
1" Vernier Micrometer	162	0.0001	43
2" Vernier Micrometer	138	0.0001	17
6" Vernier Micrometer	131	0.0001	11
3" Regular Micrometer	146	0.001	64
Depth Micrometer	142	0.001	53
Inside Micrometer	117	0.001	66
Inside Caliper & 2" Mic	127	0.001	46
Inside Caliper & 6" Mic	112	0.002	9
Outside Caliper & 6" Rule	117	0.01563	49
Inside Vernier Caliper	113	0.001	42
Outside Vernier Caliper	117	0.001	51

scarcely one inspector in 10. A 6-inch micrometer combined with an inside caliper was the most difficult to read within the established tolerance.

One incidental finding was that micrometer reading accuracy did not correlate with age, amount of experience with the company, or length of time on the present job.

Kennedy (26) briefly mentions some data obtained on a series of visual and gaging inspections. No fuller description is given, nor is the number of inspectors mentioned. Some 30,000 units were submitted, of which 100 were defective. Four groups of inspectors were used; three squads of regular inspectors under normal incentive speed, and one selected squad of experts. The only measure of accuracy that can be computed from the data given by Kennedy is the proportion of defects correctly rejected. These data are given in Table 2.2.

Apparently the "experts" did no better than the regular inspectors. This fits in well with most other studies that investigate the relation between accuracy and seniority or experience.

Harris (5) performed an experiment to determine whether inspection accuracy could be correlated with the defect rate. He chose four samples containing 0.25, 1, 4, and 16 percent defective. The samples were inspected by 80 inspectors, 20 per condition, and inspection accuracies of .58, .71, .74, and .82 were obtained. The results showed a

TABLE 2.2

DEFECTS FOUND IN FOUR SUCCESSIVE VISUAL AND GAGING INSPECTIONS OF 30,000 UNITS

Submitted		Regular I	Regular II	Regular III	Experts
Good	29900				
Defective	100	→ Found 68 Left 32	→ Found 18 Left 14	→ Found 8 Left 6	→ Found 4 Left 2
Accuracy		0.6800	0.5625	0.5714	0.6667

high positive correlation, the higher the defect rate the higher the inspection accuracy.

In a similar study Harris (6) performed an experiment to determine whether inspection accuracy could be correlated with equipment complexity. He chose 10 equipment items of increasing complexity and selected 62 inspectors who regularly inspected these items. He obtained a linear relationship between complexity and inspection accuracy, with the least complex item showing an inspection accuracy of .70 and the most complex item showing an inspection accuracy of .20.

Mackworth (11) showed that vigilance deteriorates considerably with time for tasks requiring intense attention. In a visual watching of signals, 16 percent were missed the first half hour, but 26 percent in the second.

Previously it was noted that McKenzie (14) recommended that one approach to "building in" the check is to put through from time to time a batch of work with deliberately introduced defectives. The proportion of errors discovered would give a measure of accuracy of inspection. The defectives must be easily identifiable by the experimenter, without spoiling the test. One method used for example by Belbin (2) was to stain them with invisible dye that fluoresces under ultra-violet light, thus the inspector's decisions can be quickly checked. Similarly to determine the accuracy of inspecting brass screw inserts Forster-Cooper (4) had blind inserts deliberately introduced into

each batch. But these were made of steel and brass-plated: thus mis-sorts could easily be picked out by means of a magnet.

An overall review of the available studies shows that considering the importance of inspection to the industrial community, the lack of studies is lamentable. The experimental designs are often naive, and the incomplete reporting of results and methodology would often cause the careful analyst to reject their results. The studies often do not state how inspection accuracy was calculated. The next chapter indicates that this could be a major fault since five possible methods of calculating inspection accuracy are discussed. There were no studies found involving inspection accuracy during the industrial process and recommending procedures of measuring this accuracy. The purpose of this dissertation is to explore possible methods of determining inspection accuracy in the industrial environment.

CHAPTER III

MEASURES OF INSPECTOR ACCURACY

The present section will consider the question of how inspector accuracy can be quantified. The topic is not as simple and straightforward as it might first appear. Before deriving possible measures the following symbols need to be defined.

DDI Number of defective items observed to be defective by the inspector.

DGI Number of defective items observed to be good by the inspector.

GGI Number of good items observed to be good by the inspector.

GDI Number of good items observed to be defective by the inspector.

The accuracy measures discussed will be illustrated by the following two examples of data obtained from the literature. Both examples represent results obtained under controlled experiments; however, they are two of the few found in the literature which contained all four pieces of data defined above.

Jacobson (8) became concerned with the ability of inspectors to detect poor solder connections. For the experiment a small wired unit with 1,000 wires soldered to terminals was built with 20 deliberate defects. Thirty-nine inspectors were given one and one-half hours to inspect the unit, the average inspection time on the regular inspection line. Out of a possible 780 defects and 38,220 good joints, the following sample values were obtained:

DDI = 646

GGI = 38,195

DGI = 134

GDI = 25.

Jacobson investigated many aspects of his data. No defect was found by all inspectors. Similarly, no defect was missed by all of the inspectors. Only four of the inspectors found all 100 percent of the defects; however, two of them called some of the good solder connections defective. One inspector found only nine of the 20 defects indicating a sizable difference in the accuracy of the inspectors.

Kelly (24) was interested in the inspection of television panels for appearance defects. Ten panels were selected, of which four were defective. Her main purpose was to evaluate a new method of inspection by comparing it with the inspection method in current use. The 10 panels were inspected by 14 inspectors, yielding 140 inspections; however, one good panel was lost when evaluating the new inspection method, yielding 126 inspections.

Kelly obtained the following results:

Old method of inspection:

DDI = 16

DGI = 40

GGI = 55

GDI = 29.

New method of inspection:

DDI = 51

DGI = 5

GGI = 63

GDI = 8.

Further comments on the above data will be made in the following discussion on possible measures of inspector accuracy.

Ratio of Correct Inspections

If the interest is to maximize the total number of correct inspection decisions or minimize all errors of misclassification, the following measure would be of interest:

$$ACI = \frac{GGI + DDI}{NI} .$$

In terms of the example data previously noted, we would obtain for the solder connection inspectors:

$$ACI = \frac{38,195 + 646}{39,000} = .9959 .$$

In other words 99.59 percent of the inspection decisions were correct. The assumption is that both errors, rejection of good and acceptance of bad, are equally important. For the other example involving television panels we would obtain:

$$\text{ACI (old method)} = \frac{55 + 16}{140} = .507$$

and

$$\text{ACI (new method)} = \frac{62 + 51}{126} = .897 .$$

This measure of accuracy shows a 39 percent increase in inspection accuracy involving correct inspections.

Utility Approach to Accuracy

Many times the assumption that both types of inspection errors are equally important does not fit the practical situation, and a utility theory approach might be considered appropriate. If for each of the four possible inspection outcomes, a dollar value could be determined, we can use the following function to determine the expected value.

$$AU = \frac{GGI}{NI} V(GGI) + \frac{GDI}{NI} V(GDI) + \frac{DDI}{NI} V(DDI) + \frac{DGI}{NI} V(DGI)$$

where

AU An accuracy measure based on a utility approach,

V(GGI) Value to the company of inspection determining a good unit to be good,

and

V(GDI), V(DGI), V(DDI) are defined as V(GGI) above.

Consider the Jacobson data and assume the following utility values:

V(GGI) = +1

V(DDI) = +1

V(GDI) = -1

V(DGI) = -6.

Considerations involved in the above allocations would include that rejection of good material would only involve reinspection costs and, therefore, was given a value of minus one; however, the acceptance of defective material would result in failures by the customer resulting in loss of customer good will and possible liability claims. We obtain

$$AU = \frac{1(38,195) - 1(25) - 6(134) + 1(646)}{39,000}$$

$$= .975.$$

The .975 would express the utility to the company of the inspection process; however, it does not provide a measure of the satisfactory product being shipped to the consumer and, therefore, will not be considered any further in this paper.

Ratio of Good Product Accepted

In some situations, one might be interested in maximizing the probability of accepting good product or minimizing the probability of rejecting good. In this case, accuracy would be measured by the following equation:

$$AGA = \frac{GGI}{GGI + GDI} .$$

For the Jacobson data:

$$AGA = \frac{38,195}{38,195 + 25} = .9993 .$$

For the Kelly data:

$$AGA \text{ (old method)} = \frac{55}{55 + 29} = .655$$

and

$$AGA \text{ (new method)} = \frac{62}{62 + 8} = .886 .$$

The question is, when would a situation arise that would allow the ratio of good product accepted be an appropriate measure of inspector accuracy? Presumably, in cases where the cost of the product is very high and one would want to avoid the rejection of good product at all costs.

Juran (22) feels that any measure involving the percentage of good pieces identified is not a measure of the accuracy of the inspector. His argument is that because the majority of product submitted to inspection consists of good pieces, the inspector does not exert much effort to identify correctly good pieces. Effort, however, is not the real concern, the search is for a measure of accuracy and not how hard the inspector is working.

A more reasonable argument against this measure would be to consider a batch of 100 items of which five are defective. The inspector could call all the pieces good without inspection and claim a 100 percent accuracy in

identifying good pieces. Rather than being absurd, it is the most intelligent thing for the inspector to do under the circumstances. If the company's purpose is best served by maximizing the probability of accepting good product this is what the inspector should do, and his performance should be evaluated accordingly.

This measure, however, does not involve any measures of the quality of the product reaching the consumer. Only measures involving the correct identification of defective units will be sufficient for this purpose. The two measures in the following section each have this characteristic.

Ratio of Defective Product Rejected

In some situations it is desirable to maximize the probability of rejecting defective product or minimize the probability of accepting defective product. The following accuracy function would be appropriate:

$$ADR = \frac{DDI}{DDI + DGI} .$$

For the Jacobson data:

$$ADR = \frac{646}{646 + 134} = .828 .$$

For the Kelly data:

$$ADR \text{ (old method)} = \frac{16}{16 + 40} = .286$$

and

$$ADR \text{ (new method)} = \frac{51}{51 + 5} = .911 .$$

Therefore 82.8 percent of the defective soldered joints were rejected in the Jacobson example, while the percent defective rejected in the Kelly data was increased by 62.5 percent.

This measure of accuracy appears to be one that is useful in many common circumstances; however, it concentrates on defects and ignores the rejection of good items. This may not be serious, as most rejects are returned for rework and, if found not to be defective, are returned to the line. This is the measure of accuracy used in most of the published research located. Most inspectors feel that the accurate identification of defects is the key inspection problem. Sampling plans for this measure are developed in subsequent chapters.

Juran and Gryna (23) discuss this measure of accuracy; however, they worry about the event of an inspector classifying good pieces as being defective and recommend subtracting GDI from both the numerator and denominator. For the Jacobson data we would obtain the following:

$$\text{Accuracy} = \frac{646 - 25}{646 + 134 - 25} = .8225 .$$

It is felt that this corrects for type 1 errors; however, even if this is the case, the correction destroys the simple interpretation of ADR. Accuracy is not 82.25 percent of anything simple or clear, a characteristic which makes the measure unusable.

Accuracy of Product Improvement

As noted earlier the purpose of the inspection department is to screen out defective material. The amount of product improvement resulting from the screening process could be used as a measure of inspector accuracy. The ratio of good material received from manufacturing to the total amount received prior to inspection can be called the manufacturing quality level (MQL) and can be determined from the following:

$$MQL = \frac{GGI + GDI}{NI} .$$

After the inspection process the ratio of good items to the number of items determined to be good by the inspector can be called the outgoing quality level (OQL) and can be determined from the following:

$$OQL = \frac{GGI}{GGI + DGI} .$$

The maximum amount of quality improvement is

$1 - MQL$.

The observed amount of quality improvement is

$OQL - MQL$.

The accuracy of product improvement can be given as the ratio of the above differences:

$$API = \frac{OQL - MQL}{1 - MQL} .$$

For the Jacobson data the following results are obtained:

$$MQL = \frac{38,195 + 25}{39,000} = .9800,$$

$$OQL = \frac{38,195}{38,195 + 134} = .9965,$$

$$API = \frac{.9965 - .9800}{1 - .9800} = .8250.$$

In this case the inspectors were 82.50 percent accurate in the improvement of the product, or they made 82.50 percent of the maximum amount of improvement possible.

For the Kelly data the following results are obtained:

$$MQL \text{ (old method)} = \frac{55 + 29}{140} = .600$$

$$OQL \text{ (old method)} = \frac{55}{55 + 40} = .579$$

$$API \text{ (old method)} = \frac{.579 - .600}{1 - .600} = -.053$$

$$MQL \text{ (new method)} = \frac{62 + 8}{126} = .556$$

$$OQL \text{ (new method)} = \frac{.925 - .556}{1 - .556} = .831$$

$$API \text{ (new method)} = \frac{.831 - .556}{1 - .556} = .619.$$

The most interesting result is the negative value of API obtained under the old method of inspection meaning that the company would have been better off if no inspection had been performed. While the percent of defectives rejected for the Kelly data for the old method was 28.5 percent, it was not zero, leading to the conclusion that the inspectors may be doing some good. This incorrect

conclusion would not be reached if API had been calculated.

Summary

Several measures of inspector accuracy were derived and discussed. Each has its special merits and limitations, but all of them do lead to a better understanding of accuracy.

Table 3.1 summarizes the accuracy measures derived and the quantitative results obtained from the two examples. An interesting result is shown in this table for the new inspection method of television panels; the ratio of good product accepted is less than the ratio of bad product rejected, refuting Juran's statement noted earlier that less effort is required to determine good units as good. The table shows the wide variety in quantitative measures of inspector accuracy that are possible from the same set of data.

TABLE 3.1

SUMMARY OF ACCURACY MEASURES OBTAINED FROM
TWO SETS OF SAMPLE DATA

Accuracy Measure	Solder Connection Example	Television Panels	
		Old Inspection Method	New Inspection Method
ACI = Ratio of Correct Inspections	.996	.507	.897
AGA = Ratio of Good Product Accepted	.999	.654	.886
ADR = Ratio of Defective Product Rejected	.828	.286	.911
API = Accuracy of Product Improvement	.825	-.053	.831

CHAPTER IV

EXPECTED VALUES FOR THE SAMPLING DISTRIBUTION OF THE RATIO OF DEFECTIVE PRODUCT REJECTED

This section will develop the expected values for the accuracy measure based on the ratio of defective product rejected. The two expected values to be derived for the sampling distribution of the ratio of defective product rejected are the mean and the variance. The expected values to be derived are based on a reinspection by an auditor who will either reinspect 100 percent of the product or a sample of the product that was previously accepted by the inspector. The following terms need to be defined.

NI the number of items inspected by the inspector.

DI the number of items observed to be defective by the inspector.

GI the number of items observed to be good by the inspector.

PI the inspection fraction defective.

NR the number of items reinspected by the auditor.

DR the number of items observed to be defective when reinspected by the auditor.

GR the number of items observed to be good when reinspected by the auditor.

PR the auditor fraction defective.

MQL manufacturing quality level.

IOQL the product quality level after initial inspection.

OQL product quality level after audit inspection.

The derivations will assume that the number of good items observed to be defective (GDI) is zero or is negligible. When a unit is rejected by inspection it is usually returned to the manufacturing area for disposition; scrap, rework, or resubmit to inspection. If a good unit is rejected it will be resubmitted to inspection and re-enter the flow of good product. Whatever the value of GDI it will not affect the outgoing quality level.

Two different cases will be developed for the situation where manufacturing is responsible for the lot size, by the submission of a predetermined NI to be submitted to inspection.

Case 1: The auditor performing the reinspection is perfect, or auditor accuracy = 100 percent.

Case 2: The auditor performing the reinspection has the same accuracy as the initial inspector.

The two cases should represent the extremes in the capability of the auditor. It is unreasonable to assume that a company would select for the audit function a person whose accuracy is less than that of the initial inspector.

Many manufacturing companies predetermine the lot size as the number of units required after the initial inspection, or GI. The necessary modifications to the functions derived will be discussed for this situation.

The following expected values will be determined.

$\mu(ADR)$ = mean value for the sampling distribution of the ratio of defective product rejected.

$\sigma^2(ADR)$ = variance for the sampling distribution of the ratio of defective product rejected.

Tables of comparative values for each of the expected values for different assumed values of NI, PI, NR, and PR are included in the next chapter.

Case 1 - Perfect Auditor

From the previous chapter, the equation for inspection accuracy based on the ratio of defective product rejected was given as

$$ADR = \frac{DDI}{DDI + DGI} .$$

Since we have assumed that GDI equals zero,

$$DDI = DI.$$

An estimate of DGI, the number of defective items determined to be good by the initial inspector would be given by

$$DGI = \frac{(GI)\ (DR)}{NR} ,$$

therefore

$$ADR = \frac{DI}{DI + \frac{(GI)\ (DR)}{NR}} .$$

Dividing both the numerator and denominator by NI, we have

$$ADR = \frac{\frac{DI}{NI}}{\frac{DI}{NI} + \left(1 - \frac{DI}{NI}\right)\left(\frac{DR}{NR}\right)} .$$

We can define the following expected values

$$E\left[\frac{DI}{NI}\right] = PI$$

$$E\left[\frac{DR}{NR}\right] = PR \ .$$

If DI/NI and DR/NR are independent variables we can write the expected value of ADR as (25, p. 52)

$$\mu(ADR) = \frac{PI}{PI + (1-PI)PR} \ .$$

Intuitively the number of defectives found by two different inspectors should vary independently as a function of his own capability. The assumption of independence is further strengthened by the results of the simulation analyses given in Chapter VI.

Since ADR is a function of the two random variables PI and PR, it is necessary to use the following equation (1, p. 232) for determining the variance of ADR.

$$\sigma^2(g) = \left(\frac{\partial g}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial g}{\partial y}\right)^2 \sigma_y^2 + 2 \frac{\partial g}{\partial x} \frac{\partial g}{\partial y} \rho \sigma x \sigma y.$$

For our problem the above equation would be written as

$$\sigma^2(ADR) = \left(\frac{\partial ADR}{\partial PI}\right)^2 \sigma^2(PI) + \left(\frac{\partial ADR}{\partial PR}\right)^2 \sigma^2(PR) + 2 \frac{\partial ADR}{\partial PI} \frac{\partial ADR}{\partial PR}$$

$$\rho\sigma(PI) \ \sigma(PR).$$

It can be argued that the number of defects found by the initial inspector and the reinspector should be independent and therefore $\rho = 0$. If PI and PR are correlated it should

be in a positive direction. As shown below the partial derivative with respect to PI is positive while the partial derivative with respect to PR is negative. Therefore, the last term in $\sigma^2(ADR)$ is either 0 or negative. The variances derived below will exclude the last term and at worst case will be a conservative approximation of the true variance.

Since PI and PR follow binomial distributions we have

$$\sigma^2(PI) = \frac{PI(1-PI)}{NI}$$

and

$$\sigma^2(PR) = \frac{PR(1-PR)}{NR} .$$

The partial derivatives of ADR are given as

$$\frac{\partial ADR}{\partial PI} = \frac{[PI + PR(1-PI)]\ (1)\ -PI(1-PI)}{[PI + PR(1-PI)]^2}$$

$$= \frac{PR}{[PI + PR(1-PI)]^2} ,$$

and

$$\frac{\partial ADR}{\partial PR} = \frac{[PI + PR(1-PI)](0)-PI(1-PI)}{[PI + PR(1-PI)]^2}$$

$$= - \frac{PI(1-PI)}{[PI + PR(1-PI)]^2} .$$

Combining the above terms we obtain

$$\sigma(ADR) = \frac{(PR)(PI)(1-PI)}{[PI + PR(1-PI)]^2} \sqrt{\frac{1}{(NI)(PI)(1-PI)} + \frac{1-PR}{(NR)(PR)}} .$$

To determine the expected value of the manufacturing quality level we apply the following modification to the equation given in Chapter III.

$$MQL = \frac{GGI + GDI}{NI} = 1 - \frac{DDI + DGI}{NI} ,$$

since

$$DDI = DI,$$

and

$$DGI = \frac{(GI)(DR)}{NR} .$$

Using the expected values for NI/DI and NR/DR we obtain the following

$$\mu(MQL) = 1\text{-}PI - (1\text{-}PI)PR.$$

The true fraction defective in the inspection sample is 1-MQL.

The outgoing quality level can be determined at two points in the production flow, immediately after the initial inspection (IOQL) or after the reinspection (OQL) is performed. If the reinspection is not performed on every lot but is performed on an item only periodically then the IOQL would be more representative of the outgoing quality level. If reinspection is a normal part of the production process then the OQL would be more representative of the outgoing quality level.

The general equation for the outgoing quality level was given as

$$OQL = \frac{GGI}{GGI + DGI} .$$

For the IOQL we have that

$$GGI + DGI = GI,$$

and

$$GGI = GI\left(1-\frac{DR}{NR}\right),$$

therefore

$$IOQL = 1 - \frac{DR}{NR},$$

or

$$\mu(IOQL) = 1 - PR.$$

For the OQL we have that

$$GGI + DGI = GI - DR$$

and

$$GGI = GI\left(1 - \frac{DR}{NR}\right).$$

Solving we obtain

$$OQL = \frac{GI\left(1 - \frac{DR}{NR}\right)}{GI - DR}.$$

Substituting the appropriate expected values in order to have OQL as a function of NI, NR, PI and PR we obtain

$$\mu(OQL) = 1 - \frac{(NI)(PR)(1-PI) - (NR)(PR)}{(NI)(1-PI) - (NR)(PR)}.$$

Using the manufacturing quality level and the two measures of outgoing quality level, we can obtain two measures of the accuracy of product improvement, one before reinspection and one after reinspection.

$$IAPI = \frac{IOQL - MQL}{1 - MQL}$$

and

$$API = \frac{OQL - MQL}{1 - MQL}.$$

The above equations will hold for all the cases and, therefore, will not be discussed in the following paragraphs.

Case 2 - Auditor Accuracy Equal to ADR

The following expected values are derived on the assumption that the accuracy of the reinspector is equal to that of the initial inspector.

Let

DR* = absolute number of defects submitted to reinspection,

and

DR = the observed number of defects found by reinspection.

By the definition of ADR,

$$ADR = \frac{DR}{DR^*}$$

and

$$ADR = \frac{DDI}{DDI + DGI} .$$

Since

DDI=DI,

and

$$DGI = \frac{(GI)(DR^*)}{NR} = \frac{(GI)(DR)}{(NR)(ADR)} ,$$

we obtain

$$ADR = \frac{DI}{DI + \frac{(GI)(DR)}{(ADR)(NR)}} .$$

Solving for ADR and substituting the expected values for DI/NI and DR/NR we obtain

$$\mu(ADR) = \frac{PI - (1-PI)PR}{PI} .$$

Since this function is also non-linear it is necessary to obtain the standard deviation using the same method as used in Case 1. The partial derivatives of ADR are given as

$$\frac{\partial ADR}{\partial PI} = \frac{PI(1+PR) - [PI-PR(1-PI)](1)}{PI^2} = \frac{PR}{PI^2}$$

$$\frac{\partial ADR}{\partial PR} = - \frac{PI(1-PI) - [PI-PR(1-PI)](0)}{PI^2} = - \frac{(1-PI)}{PI} .$$

Combining the above terms with $\sigma^2(PI)$ and $\sigma^2(PR)$ we obtain

$$\sigma ADR = \frac{PR(1-PI)}{PI} \sqrt{\frac{1}{(NI)(PI)(1-PI)} \quad \frac{1-PR}{(NR)(PR)}}.$$

Using the methods previously discussed for Case 1 we obtain the following additional expected values for Case 2.

$$\mu(MQL) = 1 - PI - \frac{(1-PI)PR}{ADR} .$$

$$\mu(IOQL) = 1 - \frac{PR}{ADR} .$$

$$\mu(OQL) = 1 - \frac{(NI)(PR)(1-PI)-(NR)(PR)(ADR)}{ADR[NI(1-PI)-(NR)(PR)]} ,$$

The equations derived for Cases 1 and 2 are summarized in Table 4.1.

TABLE 4.1

SUMMARY OF EXPECTED VALUE FUNCTIONS

Expected Value	CASE 1 Auditor Accuracy = 100%	CASE 2 Auditor Accuracy = Inspection Accuracy
$\mu(ADR)$	$\frac{PI}{PI + (1-PI)PR}$	$\frac{PI-(1-PI)PR}{PI}$
$\sigma(ADR)$	$\frac{(PR)(PI)(1-PI)}{[PI+PR(1-PI)]^2}\sqrt{\frac{1}{(NI)(PI)(1-PI)} + \frac{1-PR}{(NR)(PR)}}$	$\frac{PR(1-PI)}{PI}\sqrt{\frac{1}{(NI)(PI)(1-PI)} + \frac{1-PR}{(NR)(PR)}}$
$\mu(MQL)$	$1-PR-(1-PI)PR$	$1-PI - \frac{(1-PI)PR}{ADR}$
$\mu(IOQL)$	$1-PR$	$1 - \frac{PR}{ADR}$
$\mu(OQL)$	$1 - \frac{(NI)(PR)(1-PI)-(NR)(PR)}{(NI)(1-PI)-(NR)(PR)}$	$1 - \frac{(NI)(PR)(1-PI)-(NR)(PR)(ADR)}{ADR[NI(1-PI)-(NR)(PR)]}$

Sampling Statistics with Replacement

The preceding cases can be considered to be non-replacement situations since the manufacturing unit produces NI items and the defective items are not replaced during the production process.

If the number of items to be produced by the manufacturing facility is GI, meaning that all defective items need to be replaced with good items until GI items complete inspection, we have a case of inspection with replacement. Since GI is specified, it is necessary to determine NI, by

$$NI = \frac{GI}{1-PI} \quad .$$

This equation will give the number of items that need to be produced by the manufacturing facility, in order to obtain GI items when the inspection reject rate is PI. This value of NI can be substituted into the equations previously derived. Since inspection with replacement is similar to inspection with no-replacement it will not be discussed separately in the remainder of the dissertation.

Summary

Table 4.1 lists the equations for each of the expected values derived in this chapter. Figure 4.1 through 4.4 graphically show typical flow diagrams of product for the two sets of equations as well as the two special cases.

Figure 4.1 shows a typical production flow for the case where the auditor is assumed to be perfect. The following values have been assumed:

PI = .200

PR = .125

NI = 1000

NR = 160.

The expected values are calculated at the various points in the flow diagram. The number of actual good units and bad units are noted at each point on the flow diagram.

Figure 4.2 uses the same assumed values as Figure 4.2, the only difference being that the accuracy of the reinspector is equal to that of the initial inspector.

Figure 4.3 is a flow diagram where GI is specified instead of NI, therefore, the following values have been assumed:

PI = .200

PR = .125

GI = 1000

NR = 160.

The assumption of a perfect inspector is made in Figure 4.3, while the assumption of the accuracy of the auditor equal to the initial inspection is made for Figure 4.4.

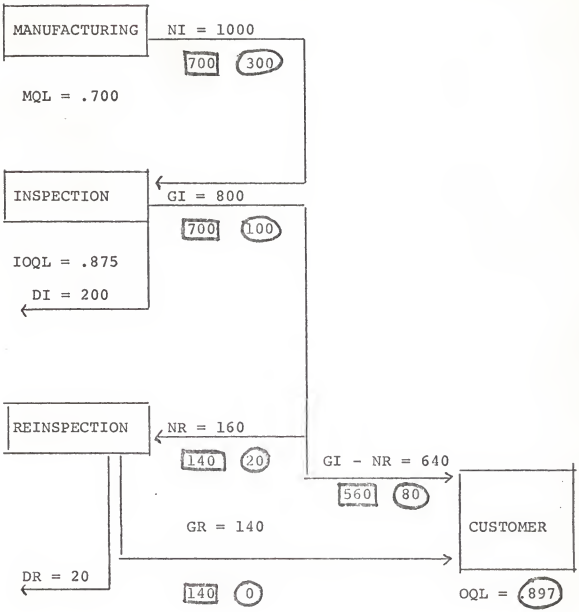

Figure 4.1

Sample Production Flow for Case 1 with No Replacement, Audit Accuracy = 100 Percent

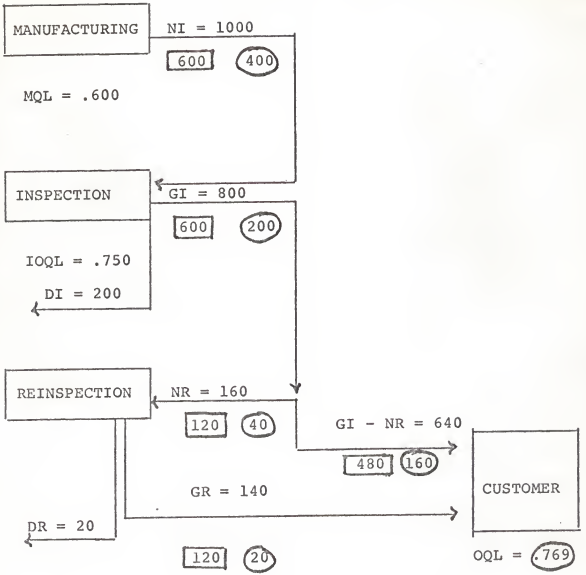

Figure 4.2

Sample Production Flow for Case 2 with No Replacement, Audit Accuracy = Inspection Accuracy

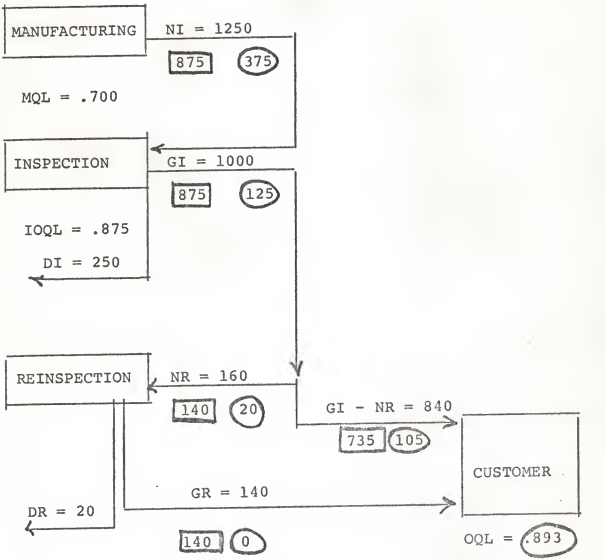

Figure 4.3

Sample Production Flow for Case 1 with Replacement, Audit Accuracy = 100 Percent

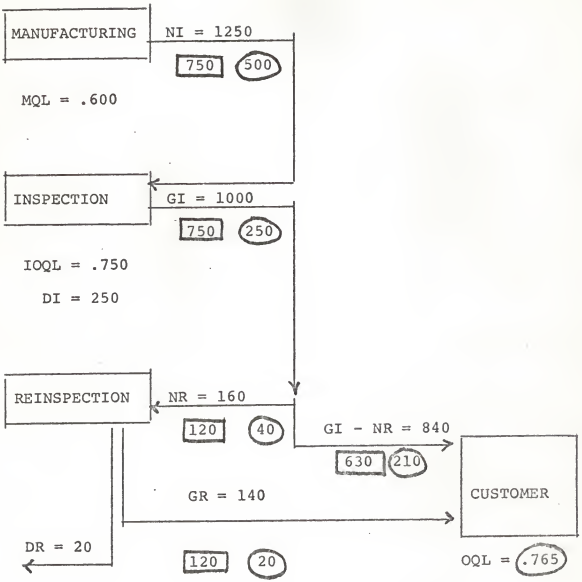

Figure 4.4

Sample Production Flow for Case 2 with Replacement,
Audit Accuracy = Inspection Accuracy

CHAPTER V

CALCULATION OF EXPECTED VALUES

This chapter evaluates the expected value functions given in Table 4.1 of the previous chapter for various inspection and audit fraction defective. The following expected values are calculated for each of the two cases:

$\mu(ADR)$ = accuracy

$\sigma(ADR)$ = accuracy standard deviation

$\mu(MQL)$ = manufacturing quality level

$\mu(OQL)$ = outgoing quality level

Seven tables are given at the end of this chapter. Each table is determined by the inspection sample size and the inspection fraction defective (PI) which is noted at the top of the table. Within each table the audit sample size and the audit fraction defective are assigned different values in order to see the effects on the calculated expected values over a wide range of values. It is to be noted that the inspection fraction defective (PI) and the audit fraction defective (PR) are expected values and are the parameters of their respective binomial distributions.

For example Table 5.1 is based on an inspection sample size of 100 and a PI of .05. If the auditor reinspects

100 percent of the product that passes inspection the audit sample size would be 95, which is listed as the first group of numbers in the first column. Within an audit sample size an assumed set of increasing values for the audit fraction defective is used to calculate $\mu(ADR)$, $\sigma(ADR)$, $\mu(MQL)$, and $\mu(OQL)$ for both Case 1 and Case 2. In Table 5.1 a similar set of calculations is performed for audit sample sizes of 50, 20, and 10.

The equation for $\mu(ADR)$ for Case 2 given below

$$\mu(ADR) = \frac{PI - (1-PI)PR}{PI}$$

will result in negative values for some values of the audit fraction defective greater than the inspection fraction defective. Those cases which result in values of negative accuracy are denoted by "Invalid for Case 2."

The situations which are invalid for Case 2 arise from the assumption that the auditors accuracy is equal to that of the initial inspector. Consider the following example for Case 2.

Inspection sample size = 100

Inspection fraction defective = .10

Audit sample size = 50

Audit fraction defective = .10

Then

$$\mu(ADR) = \frac{.10 - (.90)(.10)}{.10} = .10 .$$

If the accuracy of the inspector is .10 this means the whole inspection sample is defective, which is verified by the equation for $\mu(MQL)$ for Case 2

$$\mu(MQL) = 1 - PI - \frac{(1-PI)(PR)}{ADR}$$

$$= 1 - .10 - \frac{(.90)(.10)}{.10} = 0.$$

If the audit fraction defective is greater than the inspection fraction defective, negative values for $\mu(MQL)$ will result, which is an impossibility. If in the accumulation of actual sampling data the above situations arise, the assumption regarding the accuracy of the auditor should be re-examined.

Summary

The first observation that is apparent is that sampling plans for the accuracy will involve inspection sample sizes that are fairly large. To have a reasonable sampling plan to test whether inspection accuracy is equal to .90, the expected value of the accuracy should be greater than .90 and the standard deviation should be small, less than .05. In Table 5.1 with NI = 100 and PI = .05, no calculated value of the accuracy is greater than .8333 and the standard deviations are fairly large. In Tables 5.2 and 5.3 NI = 100, and PI = .10 and .25, the standard deviations are all fairly large. In developing the sampling plans of Chapters VII and VIII, the difficulty involving small lot sizes was readily apparent.

The following paragraphs summarize the effect of changes in the accuracy and the accuracy standard deviation as a function of the inspection and reinspection sample sizes and the inspection fraction defective. Only the noted characteristic changes while all others remain constant. The effects of changes in two or more of the above characteristics would be difficult to evaluate.

The effect of increasing the inspection sample size can be seen by comparing Table 5.1 with Table 5.5 For audit sample sizes that are the same percentage of the inspection sample size and the same audit fraction defective, the expected value for the accuracy is the same; however, the accuracy standard deviation decreases considerably as the inspection sample size increases.

The effect of increasing inspection fraction defective can be seen by comparing Table 5.1 with Table 5.2. Increasing inspection fraction defective causes the expected value for the accuracy to increase and the accuracy standard deviation to decrease.

The effect of increasing audit sample size and constant audit fraction defective can be determined by inspecting any of the tables. In this case the expected value for the accuracy remains constant while the accuracy standard deviation decreases.

The Appendix contains the computer program which can be readily modified to calculate the expected values for any inspection sample size and inspection fraction defective.

TABLE 5.1

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.05

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1				CASE 2			
		ACCURACY	STD.DEV.	MQL	OQL	ACCURACY	STD.DEV.	MQL	OQL
95	0.0105	0.8333	0.1521	0.9400	1.0000	0.8000	0.2191	0.9375	0.9973
95	0.0211	0.7143	0.1707	0.9300	1.0000	0.6000	0.3347	0.9167	0.9857
95	0.0316	0.6250	0.1712	0.9200	1.0000	0.4000	0.4382	0.8750	0.9511
95	0.0421	0.5556	0.1656	0.9100	1.0000	0.2000	0.5367	0.7500	0.8242
95	0.0526	0.5000	0.1581	0.9000	1.0000		INVALID FOR CASE 2		
95	0.0737	0.4167	0.1423	0.8800	1.0000		INVALID FOR CASE 2		
95	0.0947	0.3571	0.1281	0.8600	1.0000		INVALID FOR CASE 2		
95	0.1579	0.2500	0.0968	0.8000	1.0000		INVALID FOR CASE 2		
50	0.0200	0.7246	0.2177	0.9310	0.9904	0.6200	0.4146	0.9194	0.9780
50	0.0400	0.5682	0.2039	0.9120	0.9806	0.2400	0.6315	0.7917	0.8513
50	0.0600	0.4673	0.1802	0.8930	0.9707		INVALID FOR CASE 2		
50	0.0800	0.3968	0.1589	0.8740	0.9604		INVALID FOR CASE 2		
50	0.1000	0.3448	0.1412	0.8550	0.9500		INVALID FOR CASE 2		
50	0.1400	0.2732	0.1147	0.8170	0.9284		INVALID FOR CASE 2		
20	0.0500	0.5128	0.2691	0.9025	0.9601		INVALID FOR CASE 2		
20	0.1000	0.3448	0.1836	0.8550	0.9194		INVALID FOR CASE 2		
20	0.1500	0.2597	0.1351	0.8075	0.8777		INVALID FOR CASE 2		
10	0.1000	0.3448	0.2381	0.8550	0.9096		INVALID FOR CASE 2		

TABLE 5.2

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.10

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1				CASE 2			
		ACCURACY	STD.DEV.	MQL	DQL	ACCURACY	STD.DEV.	MQL	DQL
90	0.0111	0.9091	0.0867	0.8900	1.0000	0.9000	0.1049	0.8889	0.9988
90	0.0222	0.8333	0.1076	0.8800	1.0000	0.8000	0.1549	0.8750	0.9943
90	0.0333	0.7692	0.1169	0.8700	1.0000	0.7000	0.1975	0.8571	0.9852
90	0.0444	0.7143	0.1207	0.8600	1.0000	0.6000	0.2366	0.8333	0.9690
90	0.0667	0.6250	0.1210	0.8400	1.0000	0.4000	0.3098	0.7500	0.8929
90	0.0889	0.5556	0.1171	0.8200	1.0000	0.2000	0.3795	0.5000	0.6098
90	0.1111	0.5000	0.1118	0.8000	1.0000		INVALID FOR CASE 2		
90	0.1667	0.4000	0.0980	0.7500	1.0000		INVALID FOR CASE 2		
90	0.2222	0.3333	0.0861	0.7000	1.0000		INVALID FOR CASE 2		
50	0.0200	0.8475	0.1350	0.8820	0.9910	0.8200	0.1880	0.8780	0.9866
50	0.0400	0.7353	0.1496	0.8640	0.9818	0.6400	0.2758	0.8438	0.9588
50	0.0600	0.6494	0.1483	0.8460	0.9724	0.4600	0.3518	0.7826	0.8996
50	0.0800	0.5814	0.1421	0.8280	0.9628	0.2800	0.4205	0.6429	0.7475
50	0.1000	0.5263	0.1345	0.8100	0.9529		INVALID FOR CASE 2		
50	0.1400	0.4425	0.1193	0.7740	0.9325		INVALID FOR CASE 2		
50	0.1800	0.3817	0.1061	0.7380	0.9111		INVALID FOR CASE 2		
50	0.3000	0.2703	0.0783	0.6300	0.8400		INVALID FOR CASE 2		
20	0.0500	0.6897	0.2205	0.8550	0.9607	0.5500	0.4635	0.8182	0.9193
20	0.1000	0.5263	0.1867	0.8100	0.9205		INVALID FOR CASE 2		
20	0.1500	0.4255	0.1535	0.7650	0.8793		INVALID FOR CASE 2		
20	0.2000	0.3571	0.1281	0.7200	0.8372		INVALID FOR CASE 2		
20	0.3000	0.2703	0.0941	0.6300	0.7500		INVALID FOR CASE 2		
10	0.1000	0.5263	0.2507	0.8100	0.9101		INVALID FOR CASE 2		

TABLE 5.3

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 100, INSPECTION FRACTION DEFECTIVE = 0.25

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1				CASE 2			
		ACCURACY	STD. DEV.	MQL	OQL	ACCURACY	STD. DEV.	MQL	OQL
75	0.0133	0.9615	0.0377	0.7400	1.0000	0.9600	0.0408	0.7396	0.9994
75	0.0267	0.9259	0.0504	0.7300	1.0000	0.9200	0.0588	0.7283	0.9976
75	0.0533	0.8621	0.0640	0.7100	1.0000	0.8400	0.0862	0.7024	0.9893
75	0.0800	0.8065	0.0710	0.6900	1.0000	0.7600	0.1091	0.6711	0.9725
75	0.1200	0.7353	0.0757	0.6600	1.0000	0.6400	0.1399	0.6094	0.9233
75	0.2000	0.6250	0.0765	0.6000	1.0000	0.4000	0.1950	0.3750	0.6250
75	0.2667	0.5556	0.0741	0.5500	1.0000		INVALID FOR CASE 2		
75	0.3333	0.5000	0.0707	0.5000	1.0000		INVALID FOR CASE 2		
75	0.4667	0.4167	0.0636	0.4000	1.0000		INVALID FOR CASE 2		
75	0.6000	0.3571	0.0573	0.3000	1.0000		INVALID FOR CASE 2		
75	0.8000	0.2941	0.0494	0.1500	1.0000		INVALID FOR CASE 2		
50	0.0200	0.9434	0.0543	0.7350	0.9932	0.9400	0.0610	0.7340	0.9919
50	0.0400	0.8929	0.0699	0.7200	0.9863	0.8800	0.0876	0.7159	0.9807
50	0.0800	0.8065	0.0831	0.6900	0.9718	0.7600	0.1277	0.6711	0.9451
50	0.1200	0.7353	0.0870	0.6600	0.9565	0.6400	0.1610	0.6094	0.8832
50	0.1600	0.6757	0.0872	0.6300	0.9403	0.5200	0.1910	0.5192	0.7750
50	0.2000	0.6250	0.0856	0.6000	0.9231	0.4000	0.2191	0.3750	0.5769
50	0.3000	0.5263	0.0788	0.5250	0.8750		INVALID FOR CASE 2		
50	0.4000	0.4545	0.0716	0.4500	0.8182		INVALID FOR CASE 2		
50	0.5000	0.4000	0.0650	0.3750	0.7500		INVALID FOR CASE 2		
50	0.7000	0.3226	0.0544	0.2250	0.5625		INVALID FOR CASE 2		
50	0.9000	0.2703	0.0465	0.0750	0.2500		INVALID FOR CASE 2		
20	0.0500	0.8696	0.1136	0.7125	0.9628	0.8500	0.1502	0.7059	0.9539
20	0.1000	0.7692	0.1259	0.6750	0.9247	0.7000	0.2128	0.6429	0.8806

TABLE 5.3 CONTINUED

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 OQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 OQL
20	0.1500	0.6897	0.1242	0.6375	0.8854	0.5500	0.2611	0.5455	0.7576
20	0.2000	0.6250	0.1180	0.6000	0.8451	0.4000	0.3020	0.3750	0.5282
20	0.2500	0.5714	0.1104	0.5625	0.8036		INVALID FOR CASE 2		
20	0.3500	0.4878	0.0955	0.4875	0.7169		INVALID FOR CASE 2		
20	0.4500	0.4255	0.0827	0.4125	0.6250		INVALID FOR CASE 2		
20	0.7500	0.3077	0.0564	0.1875	0.3125		INVALID FOR CASE 2		
20	1.0000	0.2500	0.0433	0.0	0.0		INVALID FOR CASE 2		
10	0.1000	0.7692	0.1733	0.6750	0.9122	0.7000	0.2929	0.5429	0.8687
10	0.2000	0.6250	0.1578	0.6000	0.8219	0.4000	0.4040	0.3750	0.5137
10	0.3000	0.5263	0.1335	0.5250	0.7292		INVALID FOR CASE 2		
10	0.4000	0.4545	0.1118	0.4500	0.6338		INVALID FOR CASE 2		
10	0.5000	0.4000	0.0940	0.3750	0.5357		INVALID FOR CASE 2		
10	0.7000	0.3226	0.0678	0.2250	0.3309		INVALID FOR CASE 2		
10	0.9000	0.2703	0.0501	0.0750	0.1136		INVALID FOR CASE 2		
1	1.0000	0.2500	0.0433	0.0	0.0		INVALID FOR CASE 2		

TABLE 5.4

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.01

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 OQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 OQL
990	0.0010	0.9091	0.0867	0.9890	1.0000	0.9000	0.1049	0.9889	0.9999
990	0.0020	0.8333	0.1076	0.9880	1.0000	0.8000	0.1549	0.9875	0.9995
990	0.0030	0.7692	0.1169	0.9870	1.0000	0.7000	0.1975	0.9857	0.9987
990	0.0040	0.7143	0.1207	0.9860	1.0000	0.6000	0.2366	0.9833	0.9973
990	0.0061	0.6250	0.1210	0.9840	1.0000	0.4000	0.3098	0.9750	0.9909
990	0.0081	0.5556	0.1171	0.9820	1.0000	0.2000	0.3795	0.9500	0.9674
990	0.0101	0.5000	0.1118	0.9800	1.0000		INVALID FOR CASE 2		
990	0.0152	0.4000	0.0980	0.9750	1.0000		INVALID FOR CASE 2		
990	0.0202	0.3333	0.0861	0.9700	1.0000		INVALID FOR CASE 2		
500	0.0020	0.8347	0.1446	0.9880	0.9990	0.8020	0.2076	0.9875	0.9985
500	0.0040	0.7163	0.1573	0.9860	0.9980	0.6040	0.3055	0.9834	0.9954
500	0.0060	0.6274	0.1537	0.9841	0.9970	0.4060	0.3906	0.9754	0.9882
500	0.0080	0.5580	0.1457	0.9821	0.9960	0.2080	0.4679	0.9519	0.9654
500	0.0100	0.5025	0.1367	0.9801	0.9950		INVALID FOR CASE 2		
500	0.0140	0.4191	0.1197	0.9761	0.9930		INVALID FOR CASE 2		
500	0.0180	0.3595	0.1055	0.9722	0.9910		INVALID FOR CASE 2		
500	0.0300	0.2519	0.0767	0.9603	0.9849		INVALID FOR CASE 2		
200	0.0050	0.6689	0.2319	0.9851	0.9960	0.5050	0.5182	0.9802	0.9911
200	0.0100	0.5025	0.1930	0.9801	0.9920		INVALID FOR CASE 2		
200	0.0150	0.4024	0.1576	0.9752	0.9880		INVALID FOR CASE 2		
200	0.0200	0.3356	0.1312	0.9702	0.9840		INVALID FOR CASE 2		
200	0.0300	0.2519	0.0966	0.9603	0.9759		INVALID FOR CASE 2		
100	0.0100	0.5025	0.2611	0.9801	0.9910		INVALID FOR CASE 2		

TABLE 5.5

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.05

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 OQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 OQL
950	0.0011	0.9804	0.0194	0.9490	1.0000	0.9800	0.0202	0.9490	1.0000
950	0.0021	0.9615	0.0267	0.9480	1.0000	0.9600	0.0288	0.9479	0.9999
950	0.0032	0.9434	0.0317	0.9470	1.0000	0.9400	0.0357	0.9468	0.9998
950	0.0042	0.9259	0.0356	0.9460	1.0000	0.9200	0.0416	0.9457	0.9996
950	0.0053	0.9091	0.0388	0.9450	1.0000	0.9000	0.0469	0.9444	0.9994
950	0.0095	0.8475	0.0468	0.9410	1.0000	0.8200	0.0652	0.9390	0.9979
950	0.0158	0.7692	0.0523	0.9350	1.0000	0.7000	0.0883	0.9286	0.9931
950	0.0211	0.7143	0.0540	0.9300	1.0000	0.6000	0.1058	0.9167	0.9857
950	0.0316	0.6250	0.0541	0.9200	1.0000	0.4000	0.1386	0.8750	0.9511
950	0.0421	0.5556	0.0524	0.9100	1.0000	0.2000	0.1697	0.7500	0.8242
950	0.0526	0.5000	0.0500	0.9000	1.0000		INVALID FOR CASE 2		
950	0.0737	0.4167	0.0450	0.8800	1.0000		INVALID FOR CASE 2		
950	0.0947	0.3571	0.0405	0.8600	1.0000		INVALID FOR CASE 2		
950	0.1263	0.2941	0.0349	0.8300	1.0000		INVALID FOR CASE 2		
500	0.0020	0.9634	0.0356	0.9481	0.9991	0.9620	0.0384	0.9480	0.9990
500	0.0040	0.9294	0.0473	0.9462	0.9981	0.9240	0.0548	0.9459	0.9978
500	0.0080	0.8681	0.0594	0.9424	0.9962	0.8480	0.0788	0.9410	0.9948
500	0.0120	0.8143	0.0652	0.9386	0.9943	0.7720	0.0983	0.9352	0.9907
500	0.0180	0.7452	0.0685	0.9329	0.9914	0.6580	0.1234	0.9240	0.9819
500	0.0300	0.6369	0.0677	0.9215	0.9856	0.4300	0.1669	0.8837	0.9452
500	0.0400	0.5682	0.0645	0.9120	0.9806	0.2400	0.1997	0.7917	0.8513
500	0.0500	0.5128	0.0607	0.9025	0.9757		INVALID FOR CASE 2		
500	0.0700	0.4292	0.0535	0.8835	0.9656		INVALID FOR CASE 2		
500	0.0900	0.3690	0.0473	0.8645	0.9552		INVALID FOR CASE 2		
500	0.1200	0.3049	0.0401	0.8360	0.9393		INVALID FOR CASE 2		

TABLE 5.5 CONTINUED

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 DQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 DQL
200	0.0050	0.9132	0.0799	0.9453	0.9960	0.9050	0.0958	0.9448	0.9955
200	0.0100	0.8403	0.0964	0.9405	0.9921	0.8100	0.1365	0.9383	0.9897
200	0.0150	0.7782	0.1020	0.9358	0.9881	0.7150	0.1685	0.9301	0.9821
200	0.0200	0.7246	0.1029	0.9310	0.9841	0.6200	0.1960	0.9194	0.9718
200	0.0300	0.6369	0.0988	0.9215	0.9762	0.4300	0.2437	0.8837	0.9361
200	0.0400	0.5682	0.0921	0.9120	0.9682	0.2400	0.2854	0.7917	0.8404
200	0.0500	0.5128	0.0851	0.9025	0.9601		INVALID FOR CASE 2		
200	0.0750	0.4124	0.0697	0.8788	0.9398		INVALID FOR CASE 2		
200	0.1000	0.3448	0.0581	0.8550	0.9194		INVALID FOR CASE 2		
200	0.1500	0.2597	0.0427	0.8075	0.8777		INVALID FOR CASE 2		
100	0.0100	0.8403	0.1349	0.9405	0.9910	0.8100	0.1910	0.9383	0.9887
100	0.0200	0.7246	0.1426	0.9310	0.9821	0.6200	0.2717	0.9194	0.9698
100	0.0300	0.6369	0.1357	0.9215	0.9731	0.4300	0.3345	0.8837	0.9332
100	0.0400	0.5682	0.1254	0.9120	0.9641	0.2400	0.3883	0.7917	0.8369
100	0.0500	0.5128	0.1148	0.9025	0.9550		INVALID FOR CASE 2		
100	0.0700	0.4292	0.0961	0.8835	0.9369		INVALID FOR CASE 2		
100	0.0900	0.3690	0.0814	0.8645	0.9187		INVALID FOR CASE 2		
100	0.1500	0.2597	0.0536	0.8075	0.8636		INVALID FOR CASE 2		
10	0.1000	0.3448	0.2168	0.8550	0.9009		INVALID FOR CASE 2		

TABLE 5.6

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.10

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1				CASE 2			
		ACCURACY	STD.DEV.	MQL	OQL	ACCURACY	STD.DEV.	MQL	OQL
900	0.0011	0.9901	0.0099	0.8990	1.0000	0.9900	0.0100	0.8990	1.0000
900	0.0033	0.9709	0.0166	0.8970	1.0000	0.9700	0.0176	0.8969	0.9999
900	0.0056	0.9524	0.0208	0.8950	1.0000	0.9500	0.0229	0.8947	0.9997
900	0.0078	0.9346	0.0239	0.8930	1.0000	0.9300	0.0274	0.8925	0.9994
900	0.0100	0.9174	0.0264	0.8910	1.0000	0.9100	0.0313	0.8901	0.9990
900	0.0222	0.8333	0.0340	0.8800	1.0000	0.8000	0.0490	0.8750	0.9943
900	0.0333	0.7692	0.0370	0.8700	1.0000	0.7000	0.0625	0.8571	0.9852
900	0.0444	0.7143	0.0382	0.8600	1.0000	0.6000	0.0748	0.8333	0.9690
900	0.0667	0.6250	0.0383	0.8400	1.0000	0.4000	0.0980	0.7500	0.8929
900	0.0889	0.5556	0.0370	0.8200	1.0000	0.2000	0.1200	0.5000	0.6098
900	0.1111	0.5000	0.0354	0.8000	1.0000		INVALID FOR CASE 2		
900	0.1444	0.4348	0.0327	0.7700	1.0000		INVALID FOR CASE 2		
900	0.1778	0.3846	0.0302	0.7400	1.0000		INVALID FOR CASE 2		
900	0.2222	0.3333	0.0272	0.7000	1.0000		INVALID FOR CASE 2		
900	0.2889	0.2778	0.0236	0.6400	1.0000		INVALID FOR CASE 2		
500	0.0020	0.9823	0.0174	0.8982	0.9991	0.9820	0.0181	0.8982	0.9991
500	0.0040	0.9653	0.0239	0.8964	0.9982	0.9640	0.0257	0.8963	0.9981
500	0.0060	0.9488	0.0284	0.8946	0.9973	0.9460	0.0316	0.8943	0.9970
500	0.0080	0.9328	0.0319	0.8928	0.9964	0.9280	0.0367	0.8922	0.9958
500	0.0100	0.9174	0.0346	0.8910	0.9955	0.9100	0.0412	0.8901	0.9945
500	0.0120	0.9025	0.0369	0.8892	0.9946	0.8920	0.0453	0.8879	0.9932
500	0.0200	0.8475	0.0427	0.8820	0.9910	0.8200	0.0595	0.8780	0.9866
500	0.0300	0.7874	0.0461	0.8730	0.9864	0.7300	0.0743	0.8530	0.9752
500	0.0400	0.7353	0.0473	0.8640	0.9818	0.6400	0.0875	0.8438	0.9588
500	0.0600	0.6494	0.0469	0.8460	0.9724	0.4600	0.1113	0.7826	0.8996

TABLE 5.6 CONTINUED

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 OQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 OQL
500	0.0800	0.5814	0.0449	0.8280	0.9628	0.2800	0.1330	0.6429	0.7475
500	0.1000	0.5263	0.0425	0.8100	0.9529		INVALID FOR CASE 2		
500	0.1400	0.4425	0.0377	0.7740	0.9325		INVALID FOR CASE 2		
500	0.1800	0.3817	0.0336	0.7380	0.9111		INVALID FOR CASE 2		
500	0.2400	0.3165	0.0286	0.6840	0.8769		INVALID FOR CASE 2		
500	0.3200	0.2577	0.0237	0.6120	0.8270		INVALID FOR CASE 2		
200	0.0050	0.9569	0.0413	0.8955	0.9961	0.9550	0.0451	0.8953	0.9959
200	0.0100	0.9174	0.0539	0.8910	0.9922	0.9100	0.0640	0.8901	0.9912
200	0.0200	0.8475	0.0654	0.8820	0.9844	0.8200	0.0911	0.8780	0.9800
200	0.0300	0.7874	0.0696	0.8730	0.9765	0.7300	0.1122	0.8630	0.9653
200	0.0400	0.7353	0.0705	0.8640	0.9686	0.6400	0.1304	0.8438	0.9459
200	0.0750	0.5970	0.0649	0.8325	0.9407	0.3250	0.1821	0.6923	0.7823
200	0.1000	0.5263	0.0591	0.8100	0.9205		INVALID FOR CASE 2		
200	0.1250	0.4706	0.0535	0.7875	0.9000		INVALID FOR CASE 2		
200	0.1750	0.3883	0.0442	0.7425	0.8584		INVALID FOR CASE 2		
200	0.2250	0.3306	0.0372	0.6975	0.8158		INVALID FOR CASE 2		
200	0.3000	0.2703	0.0298	0.6300	0.7500		INVALID FOR CASE 2		
100	0.0100	0.9174	0.0758	0.8910	0.9911	0.9100	0.0900	0.8901	0.9901
100	0.0200	0.8475	0.0915	0.8820	0.9822	0.8200	0.1274	0.8780	0.9778
100	0.0300	0.7874	0.0968	0.8730	0.9732	0.7300	0.1551	0.8630	0.9621
100	0.0400	0.7353	0.0975	0.8640	0.9643	0.6400	0.1804	0.8438	0.9417
100	0.0600	0.6494	0.0933	0.8460	0.9463	0.4600	0.2212	0.7826	0.8754
100	0.0800	0.5814	0.0864	0.8280	0.9283	0.2800	0.2557	0.6429	0.7207
100	0.1000	0.5263	0.0793	0.8100	0.9101		INVALID FOR CASE 2		
100	0.1500	0.4255	0.0636	0.7650	0.8644		INVALID FOR CASE 2		
100	0.2000	0.3571	0.0519	0.7200	0.8182		INVALID FOR CASE 2		
100	0.3000	0.2703	0.0366	0.6300	0.7241		INVALID FOR CASE 2		
10	0.1000	0.5263	0.2380	0.8100	0.9010		INVALID FOR CASE 2		

TABLE 5.7

EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIFFERENT INSPECTION AND REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE = 1000, INSPECTION FRACTION DEFECTIVE = 0.25

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1				CASE 2			
		ACCURACY	STD.DEV.	MQL	OQL	ACCURACY	STD.DEV.	MQL	OQL
750	0.0013	0.9960	0.0040	0.7490	1.0000	0.9960	0.0040	0.7490	1.0000
750	0.0053	0.9843	0.0078	0.7460	1.0000	0.9840	0.0081	0.7459	0.9999
750	0.0093	0.9728	0.0102	0.7430	1.0000	0.9720	0.0107	0.7428	0.9997
750	0.0133	0.9615	0.0119	0.7400	1.0000	0.9600	0.0129	0.7396	0.9994
750	0.0200	0.9434	0.0142	0.7350	1.0000	0.9400	0.0159	0.7340	0.9987
750	0.0267	0.9259	0.0159	0.7300	1.0000	0.9200	0.0186	0.7283	0.9976
750	0.0333	0.9091	0.0173	0.7250	1.0000	0.9000	0.0210	0.7222	0.9962
750	0.0600	0.8475	0.0209	0.7050	1.0000	0.8200	0.0291	0.6951	0.9860
750	0.0933	0.7813	0.0231	0.6800	1.0000	0.7200	0.0379	0.6528	0.9600
750	0.1333	0.7143	0.0241	0.6500	1.0000	0.6000	0.0473	0.5833	0.8974
750	0.1733	0.6579	0.0243	0.6200	1.0000	0.4800	0.0562	0.4792	0.7728
750	0.2267	0.5952	0.0240	0.5800	1.0000	0.3200	0.0676	0.2188	0.3772
750	0.2800	0.5435	0.0232	0.5400	1.0000		INVALID FOR CASE 2		
750	0.3467	0.4902	0.0221	0.4900	1.0000		INVALID FOR CASE 2		
750	0.4267	0.4386	0.0208	0.4300	1.0000		INVALID FOR CASE 2		
750	0.5333	0.3846	0.0191	0.3500	1.0000		INVALID FOR CASE 2		
750	0.6667	0.3333	0.0172	0.2500	1.0000		INVALID FOR CASE 2		
750	0.8533	0.2809	0.0151	0.1100	1.0000		INVALID FOR CASE 2		
500	0.0020	0.9940	0.0059	0.7485	0.9993	0.9940	0.0060	0.7485	0.9993
500	0.0060	0.9823	0.0101	0.7455	0.9980	0.9820	0.0104	0.7454	0.9979
500	0.0100	0.9709	0.0128	0.7425	0.9966	0.9700	0.0135	0.7423	0.9963
500	0.0140	0.9597	0.0148	0.7395	0.9953	0.9580	0.0161	0.7390	0.9947
500	0.0180	0.9488	0.0164	0.7365	0.9939	0.9460	0.0183	0.7357	0.9929
500	0.0300	0.9174	0.0200	0.7275	0.9898	0.9100	0.0238	0.7253	0.9868
500	0.0600	0.8475	0.0248	0.7050	0.9792	0.8200	0.0345	0.6951	0.9654

TABLE 5.7 CONTINUED

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 OQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 OQL
500	0.0900	0.7874	0.0268	0.6825	0.9681	0.7300	0.0432	0.6575	0.9327
500	0.1200	0.7353	0.0275	0.6600	0.9565	0.6400	0.0509	0.5094	0.8832
500	0.1600	0.6757	0.0276	0.6300	0.9403	0.5200	0.0604	0.5192	0.7750
500	0.2000	0.6250	0.0271	0.6000	0.9231	0.4000	0.0693	0.3750	0.5769
500	0.2600	0.5618	0.0258	0.5550	0.8952		INVALID FOR CASE 2		
500	0.3200	0.5102	0.0245	0.5100	0.8644		INVALID FOR CASE 2		
500	0.4000	0.4545	0.0226	0.4500	0.8182		INVALID FOR CASE 2		
500	0.5000	0.4000	0.0206	0.3750	0.7500		INVALID FOR CASE 2		
500	0.6200	0.3497	0.0184	0.2850	0.6477		INVALID FOR CASE 2		
500	0.7800	0.2994	0.0161	0.1650	0.4583		INVALID FOR CASE 2		
200	0.0050	0.9852	0.0146	0.7463	0.9963	0.9850	0.0150	0.7462	0.9963
200	0.0100	0.9709	0.0200	0.7425	0.9926	0.9700	0.0212	0.7423	0.9923
200	0.0150	0.9569	0.0238	0.7388	0.9890	0.9550	0.0250	0.7382	0.9882
200	0.0200	0.9434	0.0267	0.7350	0.9853	0.9400	0.0300	0.7340	0.9840
200	0.0250	0.9302	0.0290	0.7313	0.9815	0.9250	0.0336	0.7297	0.9795
200	0.0300	0.9174	0.0310	0.7275	0.9778	0.9100	0.0368	0.7253	0.9748
200	0.0350	0.9050	0.0325	0.7238	0.9741	0.8950	0.0397	0.7207	0.9699
200	0.0750	0.8163	0.0388	0.6938	0.9439	0.7750	0.0582	0.6774	0.9217
200	0.1250	0.7273	0.0398	0.6563	0.9052	0.6250	0.0753	0.6000	0.8276
200	0.1750	0.6557	0.0384	0.6188	0.8654	0.4750	0.0893	0.4737	0.6625
200	0.2250	0.5970	0.0361	0.5813	0.8245	0.3250	0.1014	0.2308	0.3273
200	0.3000	0.5263	0.0325	0.5250	0.7609		INVALID FOR CASE 2		
200	0.4000	0.4545	0.0281	0.4500	0.6716		INVALID FOR CASE 2		
200	0.5000	0.4000	0.0244	0.3750	0.5769		INVALID FOR CASE 2		
200	0.6500	0.3390	0.0201	0.2625	0.4234		INVALID FOR CASE 2		
200	0.8500	0.2817	0.0160	0.1125	0.1940		INVALID FOR CASE 2		
100	0.0100	0.9709	0.0282	0.7425	0.9913	0.9700	0.0299	0.7423	0.9910
100	0.0200	0.9434	0.0376	0.7350	0.9826	0.9400	0.0422	0.7340	0.9813
100	0.0300	0.9174	0.0434	0.7275	0.9739	0.9100	0.0516	0.7253	0.9709

TABLE 5.7 CONTINUED

AUDIT SAMPLE SIZE	AUDIT FRACTION DEFECTIVE	CASE 1 ACCURACY	CASE 1 STD.DEV.	CASE 1 MQL	CASE 1 DQL	CASE 2 ACCURACY	CASE 2 STD.DEV.	CASE 2 MQL	CASE 2 DQL
100	0.0600	0.8475	0.0520	0.7050	0.9476	0.8200	0.0724	0.5951	0.9343
100	0.0900	0.7874	0.0546	0.6825	0.9211	0.7300	0.0881	0.6575	0.8874
100	0.1500	0.6397	0.0533	0.6375	0.8673	0.5500	0.1120	0.5455	0.7421
100	0.2000	0.6250	0.0499	0.6000	0.8219	0.4000	0.1277	0.3750	0.5137
100	0.2500	0.5714	0.0460	0.5625	0.7759		INVALID FOR CASE 2		
100	0.3500	0.4878	0.0386	0.4875	0.6818		INVALID FOR CASE 2		
100	0.4500	0.4255	0.0324	0.4125	0.5851		INVALID FOR CASE 2		
100	0.6000	0.3571	0.0252	0.3000	0.4348		INVALID FOR CASE 2		
100	0.8000	0.2941	0.0184	0.1500	0.2239		INVALID FOR CASE 2		
10	0.1000	0.7692	0.1689	0.6750	0.9012	0.7000	0.2854	0.5429	0.8583
10	0.2000	0.6250	0.1492	0.6000	0.8021	0.4000	0.3820	0.3750	0.5013
10	0.3000	0.5263	0.1218	0.5250	0.7028		INVALID FOR CASE 2		
10	0.4000	0.4545	0.0977	0.4500	0.6032		INVALID FOR CASE 2		
10	0.5000	0.4000	0.0779	0.3750	0.5034		INVALID FOR CASE 2		
10	0.7000	0.3226	0.0480	0.2250	0.3028		INVALID FOR CASE 2		
10	0.9000	0.2703	0.0253	0.0750	0.1012		INVALID FOR CASE 2		

CHAPTER VI

VERIFICATION OF DERIVED EXPECTED VALUES BY SIMULATION

The purpose of this chapter is to verify the previously derived equations for the expected values of the mean and the standard deviation for the distribution of the ratio of defective product rejected by the method of simulation.

A computer program utilizing random numbers was written to determine the reasonableness of the five following assumptions.

1. Is the expected value of the accuracy equal to the function given for $\mu(ADR)$ in Table 4.1?
2. Is the standard deviation of the accuracy equal to the function given for $\sigma(ADR)$ given in Table 4.1?
3. Is the assumption of zero correlation between PI and PR justifiable?
4. Is the sampling distribution of ADR unimodal?
5. Does the sampling distribution of ADR follow a normal distribution?

The purpose of the simulation was to follow as closely as possible the flow of events in a typical production line. The following steps were used in the development of the computer program. Each run through the simulation represents one lot.

1. A value for the manufacturing quality level (MQL) was predetermined. Since the actual number of defectives in a lot of fixed size will vary from lot to lot, the number of defectives in a lot was determined by simulation. The MQL follows a binomial distribution which for large lot sizes can be approximated by a normal distribution. For each lot the number of defectives in the lot (D) was determined by generating a normal random deviate (Z) and solving for D in the following equation

$$D = NI(1-MQL) + Z\sqrt{NI(MQL)(1-MQL)}.$$

2. A value for the accuracy (ADR) of the inspectors was also preselected. Since the accuracy of an inspector will vary from lot to lot, the number of defectives found by the inspector was also determined by simulation. Since ADR is the probability that an inspector will find a defective when a lot contains D defectives, ADR also follows a binomial distribution which can be approximated by a normal distribution. For each lot the number of defectives found by inspection (DI) was determined by generating a normal random deviate (Z) and solving for DI in the following equation

$$DI = (D)(ADR) + Z\sqrt{(D)(ADR)(1-ADR)}\ .$$

3. The lot PI was calculated.

4. The absolute number of defectives in the sample submitted to reinspection is also generated by the use of a random normal deviate and using the difference of the previously determined values of D and DI.

5. The number of defectives found by the inspector for Case 1 is equal to that found in Step 4 since the auditor has 100 percent accuracy. For Case 2 the number of defectives found by the auditor is a function of his accuracy and is determined in a manner similar to Step 2.

6. The lot PR is calculated.

7. For Case 1 and Case 2 the observed accuracy is determined for each lot.

8. The following statistics are calculated from the simulation where K equals the number of runs.

$$\text{Average PI} = \frac{\Sigma PI}{K}$$

$$\text{Average PR} = \frac{\Sigma PR}{K}$$

$$\text{Average Accuracy} = \frac{\Sigma ADR}{K}$$

$$\text{Accuracy Standard Deviation} = \sqrt{\frac{\Sigma ADR^2 - \frac{(\Sigma ADR)^2}{K}}{K-1}} .$$

Correlation of PI and PR for K lots.

9. The number of ADR values generated in intervals of .01 were calculated to determine if the distribution is unimodal.

10. The number of ADR values generated more than one and two standard deviations from the mean are also determined as a rough check on normality.

The above steps require only the following values as initial conditions:

μ(MQL) = population manufacturing quality level

μ(ADR) = assumed population accuracy

NI = inspection sample size

NR = reinspection sample size.

For example the following results were obtained after 1000 runs for the following initial conditions for Case 1 where the accuracy of the auditor is assumed to be 100 percent.

For the initial conditions,

μ(MQL) = .75

μ(ADR) = .90

NI = 1000

NR = 500,

the simulation results can be compared to the expected results based on the equations given in Table 4.1.

	Expected Value	Simulation Value
μ(ADR)	.9000	.9002
PI	.2250	.2252
PR	.0323	.0323
σ(ADR)	.0231	.0225

The table of frequencies for the 1000 ADR values is unimodal as shown in Figure 6.1.

For the 1000 runs 44 observations exceeded two standard deviations while 320 observations exceeded one standard deviation. This compares with 45.6 and 317.4 expected observations under the assumption of normality.

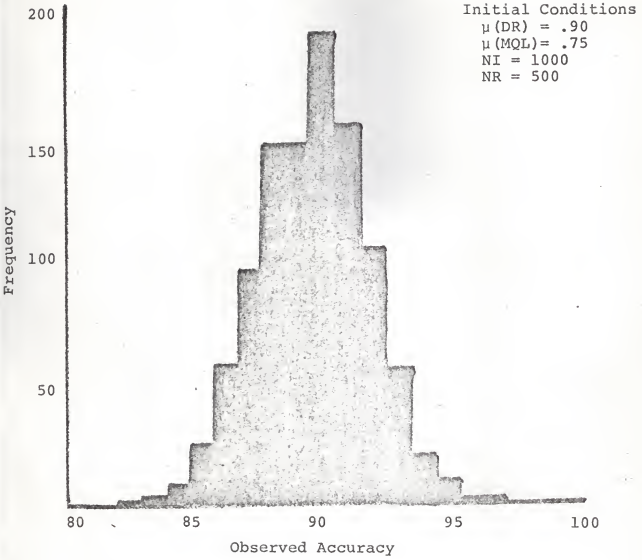

Figure 6.1
Histogram of Simulation Results

The results of the simulation are very close to the expected results from the equations that were derived in Chapter IV.

Table 6.1 gives the results of simulations where the initial conditions are NI = 1000, NR = 100, and all combinations of μ(MQL) = .50, .75, and .90 with μ(ADR) = .50, .75, and .90 for Case 1. The table lists the initial conditions, the expected values, and the observed values from the simulations for ADR σ(ADR), PI, and PR. In addition the correlation of PI and PR and the number of observations exceeding one and two standard deviations are listed.

Table 6.2 is similar to Table 6.1 except the results are for Case 2. Tables 6.3 and 6.4 are similar except that the audit sample size is 200.

Conclusions

The conclusions of this chapter based on the results of the simulations are the answers to the questions that were raised at the beginning of the chapter.

1. The expected value for the ADR is equal to the function given in Table 4.1.

2. The standard deviation of the accuracy based on the simulation results is equal to the function given in Table 4.1.

3. The correlation between PI and PR can be assumed to be equal to zero.

4. The sampling distribution for ADR appears to be unimodal.

TABLE 6.1

RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 1

NUMBER INSPECTED = 1000 NUMBER AUDITED = 500

MQL	Initial	.90	.90	.90	.75	.75	.75	.50	.50	.50
Accuracy	Initial	.90	.75	.50	.90	.75	.50	.90	.75	.50
	Observed	.9006	.7516	.5021	.9002	.7504	.5006	.9000	.7501	.5002
σ (ADR)	Expected	.0395	.0551	.0597	.0231	.0328	.0364	.0140	.0208	.0242
	Observed	.0386	.0538	.0580	.0225	.0317	.0350	.0136	.0200	.0232
PI	Expected	.0900	.0750	.0500	.2250	.1875	.1250	.4500	.3750	.2500
	Observed	.0901	.0751	.0501	.2252	.1877	.1251	.4502	.3752	.2501
PR	Expected	.0110	.0270	.0526	.0323	.0769	.1429	.0909	.2000	.3333
	Observed	.0110	.0271	.0527	.0323	.0770	.1430	.0910	.2001	.3335
Correlation		.0378	.0389	.0388	.0379	.0396	.0391	.0390	.0404	.0391
Number Greater than 1 σ		321	317	315	320	319	310	315	313	309
Number Greater than 2 σ		49	41	42	44	40	45	39	41	45

TABLE 6.2

RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 2

NUMBER INSPECTED = 1000 NUMBER AUDITED = 500

MQL	Initial	.90	.90	.90	.75	.75	.75	.50	.50	.50
Accuracy	Initial	.90	.75	.50	.90	.75	.50	.90	.75	.50
	Observed	.8993	.7484	.4943	.8999	.7496	.4985	.9000	.7500	.4996
σ(ADR)	Expected	.0461	.0833	.1542	.0269	.0495	.0937	.0163	.0312	.0619
	Observed	.0456	.0832	.1562	.0266	.0489	.0933	.0160	.0307	.0616
PI	Expected	.0900	.0750	.0500	.2250	.1875	.1250	.4500	.3750	.2500
	Observed	.0901	.0751	.0501	.2252	.1877	.1251	.4502	.3752	.2501
PR	Expected	.0099	.0203	.0263	.0290	.0577	.0714	.0818	.1500	.1667
	Observed	.0099	.0202	.0262	.0290	.0576	.0712	.0818	.1498	.1663
Correlation		.0408	.0375	.0290	.0389	.0361	.0272	.0387	.0351	.0242
Number Greater than 1 σ		309	300	307	306	309	318	313	311	316
Number Greater than 2 σ		40	42	43	41	42	43	35	45	43

TABLE 6.3

RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 1

NUMBER INSPECTED = 1000 NUMBER AUDITED = 200

MQL	Initial	.90	.90	.90	.75	.75	.75	.50	.50	.50
Accuracy	Initial	.90	.75	.50	.90	.75	.50	.90	.75	.50
	Observed	.9010	.7562	.5089	.9008	.7519	.5027	.9002	.7506	.5008
σ(ADR)	Expected	.0612	.0827	.0833	.0355	.0484	.0495	.0209	.0292	.0310
	Observed	.0565	.0821	.0851	.0347	.0472	.0482	.0204	.0282	.0298
PI	Expected	.0900	.0750	.0500	.2250	.1875	.1250	.4500	.3750	.2500
	Observed	.0901	.0751	.0501	.2252	.1877	.1251	.4502	.3752	.2501
PR	Expected	.0110	.0270	.0526	.0323	.0769	.1429	.0909	.2000	.3333
	Observed	.0112	.0271	.0528	.0324	.0771	.1431	.0911	.2002	.3336
Correlation		.0311	.0394	.0389	.0381	.0395	.0390	.0389	.0400	.0387
Number Greater than 1 σ		303	314	299	317	318	311	316	310	316
Number Greater than 2 σ		28	45	38	55	44	42	46	40	47

TABLE 6.4

RESULTS OF SIMULATION ANALYSIS BASED ON 1000 RUNS FOR CASE 2

NUMBER INSPECTED = 1000 NUMBER AUDITED = 200

MQL	Initial	.90	.90	.90	.75	.75	.75	.50	.50	.50
Accuracy	Initial	.90	.75	.50	.90	.75	.50	.90	.75	.50
	Observed	.8978	.7487	.4961	.8999	.7500	.4996	.9000	.7502	.5004
σ(ADR)	Expected	.0716	.1265	.2270	.0416	.0743	.1361	.0245	.0451	.0871
	Observed	.0683	.1265	.2311	.0410	.0737	.1365	.0242	.0446	.0869
PI	Expected	.0900	.0750	.0500	.2250	.1875	.1250	.4500	.3750	.2500
	Observed	.0901	.0751	.0501	.2252	.1877	.1251	.4502	.3752	.2501
PR	Expected	.0099	.0203	.0263	.0290	.0577	.0714	.1818	.1500	.1667
	Observed	.0101	.0202	.0261	.0290	.0575	.0710	.1817	.1497	.1660
Correlation		.0361	.0404	.0307	.0407	.0373	.0280	.0393	.0354	.0245
Number Greater than 1 σ		331	304	301	311	308	317	309	308	319
Number Greater than 2 σ		35	36	44	46	44	46	41	43	49

5. Based on the unimodal appearance of the observed sampling distribution and the observed number of samples exceeding one and two standard deviations being approximately equal to that under the assumption of normality, it may be reasonable to assume that ADR follows a normal distribution.

CHAPTER VII

SINGLE HYPOTHESIS SAMPLING PLANS FOR INSPECTION ACCURACY

It is desirable to determine whether inspection personnel have an accuracy of less than some minimum value at some predetermined confidence level. This chapter develops the audit sampling plans equivalent to the above hypothesis.

The null hypothesis for these plans is that the inspection accuracy is equal to or greater than some minimum acceptable value while the alternate hypothesis is that the inspection accuracy is less than some minimum acceptable accuracy with a fixed alpha error.

Figure 7.1 is a graphic presentation of the above described classifical statistical one-tail test. If the observed inspection accuracy plus K standard deviations is less than minimum acceptable accuracy, the alternate hypothesis would be accepted. The observed inspection accuracy and the standard deviation need to be calculated from the inspection and reinspection results and are therefore sampling statistics. The sampling statistics are obtained by substituting

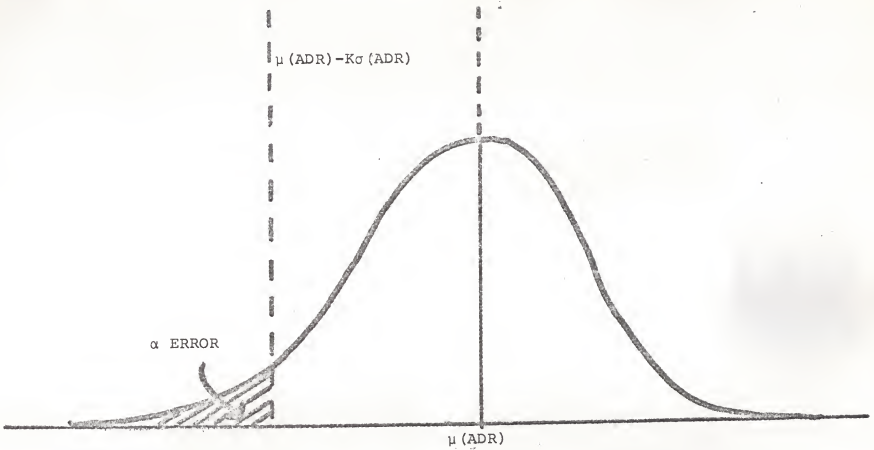

Figure 7.1

Graphical Presentation of a Single Hypothesis
Statistical Test for Inspection Accuracy

$$\frac{DI}{NI} = PI$$

$$\frac{DR}{NR} = PR$$

into the equations given in Table 4.1. For example the following equations for the sampling statistics result for the accuracy and accuracy standard deviation for Case 1.

$$ADR = \frac{(NR)(DI)}{(NR)(DI) + (NI-DI)(DR)}$$

$$S(ADR) = \frac{(NR)(DR)(DI)(NI-DI)}{[(NR)(DI) + (DR)(NI-DI)]^2}\sqrt{\frac{NI}{DI(NI-DI)}\frac{(NR-DR)}{(NR)(DR)}}\ .$$

Similar equations can be determined for Case 2. The value of K is selected on the basis of the desired alpha error.

Before sampling plans can be determined it is necessary to know something about the form of the distribution. Since we are dealing with a non-linear mathematical function consisting of two variables, the exact form of the distribution is difficult to obtain analytically.

The simulation studies of Chapter VI verified the assumption of a unimodal distribution and also lend support to the assumption of normality. Since there is no theoretical basis for the assumption of normality the fact that the distribution is unimodal permits us to use a special case of Chebyshev's inequality known as the Camp Meidel inequality (25, p. 89)

$$P[|x - \mu| > K\sigma] \leq \frac{1}{2.25\ K^2}\ .$$

For a one-tail test and for the accuracy function we can

determine an alpha error value

$$P[(ADR - \mu(ADR)) > K\,\sigma(ADR)] \leq \frac{1}{(2)\ (2.25)\ K^2}$$

where

$\mu(ADR)$ = minimum acceptable accuracy

ADR = observed accuracy.

The alpha error for the Camp Meidel inequality when K = 1.645, the normal variate for $\alpha = .05$, is

$$\alpha(\text{CAMP MEIDEL}) = \frac{1}{(2.25)(2)(1.645)^2} = .082.$$

Both alpha values are given on the following tables.

The sampling plans on the following tables were obtained by selecting inspection and audit sample sizes, and for various observed inspection fraction defective test results the number of defectives found by the auditor necessary to reject accuracies of .75 and .90 are given.

For example for an inspection sample size of 500, and an audit sample size of 250, if the inspector has an observed fraction defective of .05, the hypothesis of .75 accuracy for Case 1 would be rejected if the auditor finds 9 or more defectives.

The tables at the end of the chapter give sampling plans for inspection sample sizes of 500, 1000, 5000, and 10,000 and for audit sample sizes of 1/2, 1/5, 1/10, and 1/50 of the inspection sample sizes.

The Appendix lists the computer program for the single-hypothesis sampling plans. The computer program can be

easily modified for other alpha error values or sample sizes by modifying the data cards. If a sample size is selected that is too small, which results, in the problems discussed in Chapter V, the computer program will print "no test" instead of the required number of defectives necessary to be found by the auditor.

TABLE 7.1

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 250

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	4	2	9	7
0.020	5	3	7	6
0.030	7	4	8	6
0.040	8	5	9	6
0.050	9	5	10	6
0.060	11	6	10	6
0.080	13	7	12	7
0.100	16	8	14	8
0.120	19	9	16	9
0.140	22	10	18	10
0.160	24	11	21	11
0.180	27	12	23	12
0.200	30	13	25	13
0.250	39	16	31	16
0.300	48	20	38	19
0.350	59	23	46	22
0.400	71	28	56	26
0.450	85	33	67	31
0.500	103	39	80	36

TABLE 7.2

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 100

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	2	2	7	7
0.020	3	2	5	5
0.030	4	3	5	4
0.040	4	3	6	4
0.050	5	3	6	5
0.060	6	3	6	5
0.080	7	4	7	5
0.100	8	4	8	5
0.120	9	5	9	6
0.140	10	5	10	6
0.160	12	6	11	6
0.180	13	6	12	7
0.200	14	7	13	7
0.250	18	8	15	8
0.300	21	10	18	10
0.350	26	11	21	11
0.400	31	13	25	13
0.450	37	15	30	15
0.500	43	18	35	17

TABLE 7.3

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 50

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	1	1	6	6
0.020	2	2	5	4
0.030	2	2	4	4
0.040	3	2	5	4
0.050	3	2	5	4
0.060	4	2	5	4
0.080	4	3	5	4
0.100	5	3	6	4
0.120	6	3	6	4
0.140	6	4	7	5
0.160	7	4	7	5
0.180	8	4	7	5
0.200	8	5	8	5
0.250	10	5	9	6
0.300	12	6	11	7
0.350	14	7	13	7
0.400	17	8	14	8
0.450	20	9	17	9
0.500	23	11	19	10

TABLE 7.4

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 500, AUDIT SAMPLE SIZE = 10

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	1	1	4	4
0.020	1	1	3	3
0.030	1	1	3	3
0.040	1	1	3	3
0.050	1	1	3	3
0.060	2	1	3	3
0.080	2	1	3	3
0.100	2	2	3	3
0.120	2	2	3	3
0.140	2	2	3	3
0.160	3	2	3	3
0.180	3	2	4	3
0.200	3	2	4	3
0.250	3	2	4	3
0.300	4	3	4	3
0.350	4	3	4	3
0.400	5	3	5	4
0.450	5	3	5	4
0.500	6	4	6	4

TABLE 7.5

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 500

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	5	3	7	6
0.020	8	5	9	6
0.030	11	6	10	6
0.040	13	7	12	7
0.050	15	7	14	8
0.060	18	8	16	9
0.080	23	10	19	10
0.100	28	12	23	12
0.120	33	14	27	14
0.140	38	16	31	15
0.160	43	18	35	17
0.180	49	20	39	19
0.200	55	22	43	21
0.250	70	28	55	26
0.300	88	34	69	31
0.350	108	41	84	38
0.400	132	49	102	45
0.450	160	59	123	54
0.500	193	70	148	64

TABLE 7.6

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 200

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	3	2	5	5
0.020	4	3	6	4
0.030	5	3	6	5
0.040	7	4	7	5
0.050	8	4	8	5
0.060	9	5	9	6
0.080	11	6	10	6
0.100	13	7	12	7
0.120	15	7	13	8
0.140	17	8	15	8
0.160	20	9	17	9
0.180	22	10	19	10
0.200	25	11	20	11
0.250	31	13	25	13
0.300	38	16	31	15
0.350	47	19	37	18
0.400	56	23	45	21
0.450	67	27	53	25
0.500	81	31	63	29

TABLE 7.7

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 100

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	2	2	5	4
0.020	3	2	5	4
0.030	4	2	5	4
0.040	4	3	5	4
0.050	5	3	6	4
0.060	5	3	6	4
0.080	7	4	7	5
0.100	8	4	8	5
0.120	9	5	9	6
0.140	10	5	9	6
0.160	11	6	10	6
0.180	13	6	11	7
0.200	14	7	12	7
0.250	17	8	15	8
0.300	21	10	18	10
0.350	25	11	21	11
0.400	30	13	25	13
0.450	36	15	29	15
0.500	42	18	34	17

TABLE 7.8

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 1000, AUDIT SAMPLE SIZE = 20

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	1	1	4	4
0.020	1	1	3	3
0.030	2	1	3	3
0.040	2	1	3	3
0.050	2	2	3	3
0.060	2	2	4	3
0.080	2	2	4	3
0.100	3	2	4	3
0.120	3	2	4	3
0.140	3	2	4	3
0.160	4	3	4	4
0.180	4	3	5	4
0.200	4	3	5	4
0.250	5	3	5	4
0.300	6	4	6	4
0.350	7	4	7	5
0.400	8	5	7	5
0.450	9	5	8	5
0.500	11	6	9	6

TABLE 7.9

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE =2500

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	15	7	13	8
0.020	26	11	22	11
0.030	36	15	29	15
0.040	47	19	37	18
0.050	57	23	45	21
0.060	68	27	53	25
0.080	89	34	70	32
0.100	111	42	86	39
0.120	134	50	104	46
0.140	158	58	122	54
0.160	183	67	140	61
0.180	209	76	160	69
0.200	236	85	180	78
0.250	309	111	236	101
0.300	393	139	299	127
0.350	489	172	371	156
0.400	600	210	456	191
0.450	732	255	555	231
0.500	890	309	674	279

TABLE 7.10

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE =1000

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	8	4	8	5
0.020	12	6	11	7
0.030	17	8	15	8
0.040	21	10	18	10
0.050	26	11	21	11
0.060	30	13	25	13
0.080	39	16	32	16
0.100	48	20	39	19
0.120	58	23	46	22
0.140	68	27	53	25
0.160	78	30	61	28
0.180	89	34	69	32
0.200	100	38	78	35
0.250	130	49	100	45
0.300	164	61	126	56
0.350	202	74	155	68
0.400	247	90	189	82
0.450	300	108	229	98
0.500	363	130	277	118

TABLE 7.11

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 500

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	5	3	6	4
0.020	7	4	8	5
0.030	10	5	9	6
0.040	12	6	11	7
0.050	15	7	13	8
0.060	17	8	15	8
0.080	22	10	18	10
0.100	27	12	22	12
0.120	32	14	26	13
0.140	37	16	30	15
0.160	42	17	34	17
0.180	47	19	38	18
0.200	53	22	42	20
0.250	68	27	54	25
0.300	86	33	67	31
0.350	105	40	82	37
0.400	128	48	99	44
0.450	155	58	119	53
0.500	186	69	143	63

TABLE 7.12

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE = 5000, AUDIT SAMPLE SIZE = 100

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	2	2	4	3
0.020	3	2	4	4
0.030	3	2	5	4
0.040	4	3	5	4
0.050	5	3	5	4
0.060	5	3	6	4
0.080	7	4	7	5
0.100	8	4	8	5
0.120	9	5	8	5
0.140	10	5	9	6
0.160	11	6	10	6
0.180	12	6	11	7
0.200	14	7	12	7
0.250	17	8	15	8
0.300	21	10	17	10
0.350	25	11	21	11
0.400	30	13	24	13
0.450	35	15	28	14
0.500	42	18	33	17

TABLE 7.13

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE =10000, AUDIT SAMPLE SIZE =5000

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	26	11	21	11
0.020	46	19	37	18
0.030	66	26	52	24
0.040	86	33	67	31
0.050	106	40	82	37
0.060	126	47	98	44
0.080	168	62	129	57
0.100	211	77	162	70
0.120	256	92	196	84
0.140	302	108	231	99
0.160	351	125	267	114
0.180	401	142	306	130
0.200	455	161	346	146
0.250	599	210	455	191
0.300	764	266	579	241
0.350	953	330	721	299
0.400	1174	405	887	367
0.450	1434	493	1083	446
0.500	1746	598	1318	541

TABLE 7.14

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE =10000, AUDIT SAMPLE SIZE =2000

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	12	6	11	7
0.020	21	10	18	10
0.030	29	13	24	12
0.040	38	16	31	15
0.050	46	19	37	18
0.060	55	22	43	21
0.080	72	28	57	26
0.100	90	35	70	32
0.120	108	41	84	38
0.140	127	48	98	44
0.160	147	55	113	50
0.180	168	62	129	57
0.200	189	69	145	64
0.250	248	90	190	82
0.300	315	113	240	103
0.350	391	139	298	127
0.400	480	170	365	154
0.450	584	205	443	186
0.500	709	248	538	225

TABLE 7.15

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE =10000, AUDIT SAMPLE SIZE =1000

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	ACCURACY =0.75	ACCURACY =0.90	ACCURACY =0.75	ACCURACY =0.90
0.010	7	4	8	5
0.020	12	6	11	7
0.030	17	8	14	8
0.040	21	10	18	10
0.050	26	11	21	11
0.060	30	13	25	13
0.080	39	16	31	16
0.100	48	20	38	19
0.120	58	23	46	22
0.140	67	27	53	25
0.160	78	30	61	28
0.180	88	34	69	32
0.200	99	38	77	35
0.250	129	48	100	45
0.300	163	60	125	55
0.350	201	74	155	68
0.400	246	89	188	82
0.450	298	108	228	98
0.500	361	129	275	118

TABLE 7.16

MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY, INSPECTION SAMPLE SIZE =10000, AUDIT SAMPLE SIZE = 200

ALPHA ERROR =0.050 (NORMAL)
ALPHA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 ACCURACY =0.75	CASE 1 ACCURACY =0.90	CASE 2 ACCURACY =0.75	CASE 2 ACCURACY =0.90
0.010	3	2	4	4
0.020	4	3	5	4
0.030	5	3	6	4
0.040	6	4	7	5
0.050	7	4	7	5
0.060	9	5	8	5
0.080	11	6	10	6
0.100	13	6	11	7
0.120	15	7	13	8
0.140	17	8	15	8
0.160	19	9	16	9
0.180	22	10	18	10
0.200	24	11	20	11
0.250	30	13	25	13
0.300	38	16	30	15
0.350	46	19	36	18
0.400	55	22	43	21
0.450	66	26	52	24
0.500	78	31	61	29

CHAPTER VIII

DOUBLE HYPOTHESIS SAMPLING PLANS FOR INSPECTION ACCURACY

The sampling plans developed in this chapter are based on a null hypothesis which states that the accuracy is equal to some acceptable value and an alternate hypothesis which states that the accuracy is equal to some unacceptable value. To develop these sampling plans both the alpha and beta errors are fixed. Figure 8.1 is a graphic presentation of the above described classical statistical test. In tests of hypotheses of this type two values need to be determined. The minimum sample size necessary to reduce the standard deviation to meet the alpha and beta errors and the actual decision value need to be calculated.

The sampling plans developed are for a fixed inspection sample size. Based on an observed inspection fraction defective, the audit sample size and the number of defects in the audit sample to reject the null hypothesis are given.

For example in Table 8.1, the hypotheses are:

Null hypotheses μ_o (ADR) = .90

Alternate hypothesis μ_1 (ADR) = .50

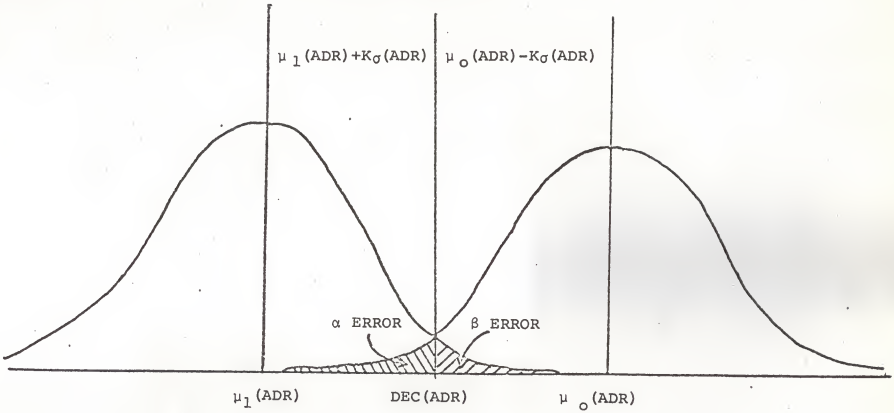

Figure 8.1

Graphical Presentation of a Double Hypothesis Test for Inspection Accuracy

If the inspection sample size is 100 and the observed inspection fraction defective is .20, the auditor should take a sample of 19 items. If 3 or more defectives are found the alternate hypothesis is accepted, if 2 or less are found the null hypothesis is accepted. Situations where the audit sample size required to reduce the standard deviation are greater than the original inspection sample size are noted by the remark that the "lot size is too small."

Tables in the back of the chapter are given for inspection sample sizes of 100, 500, 1000, and 5000, and for alternate hypotheses of $\mu_1(ADR)$ = .50, .60, and .75.

The computer program for these sampling plans is given in the Appendix and can be modified for different hypotheses, alpha and beta errors, and inspection sample sizes by modifying the data card.

The equations used to determine the audit sample sizes are based on the assumption of normality; however, the equivalent value for the alpha and beta errors for the Camp Meidel inequality were calculated and are printed in the tables.

The following procedure for Case 1 was used to determine the minimum audit sample sizes and decision criteria. For each hypothesis the following two equations are determined:

$$-Z = \frac{ADR - \mu_o(ADR)}{\sigma(ADR)}$$

$$Z = \frac{ADR - \mu_1(ADR)}{\sigma(ADR)} \quad .$$

ADR is a sampling statistic which was derived in the previous chapter as

$$ADR = \frac{(NR)(DI)}{(NR)(DI) + (NI-DI)(DR)} .$$

Since $\sigma(ADR)$ is unknown it is necessary to use an estimate obtained from the sample, which was also derived in the previous chapter as

$$S(ADR) = \frac{(NR)(DR)(DI)(NI-DI)}{[(NR)(DI) + DR(NI-DI)]^2} \sqrt{\frac{NI}{DI(NI-DI)} \quad \frac{NR-DR}{(NR)(DR)}} .$$

Substituting the functions for the sampling statistics and selecting values for the inspection sample size and the observed inspection defective into the pair of Z equations, we have two equations in two unknowns, the audit sample size (NR) and the number of audit defectives (DR).

The sampling plans developed in this chapter show that large sample sizes are necessary to adequately determine values of inspector accuracy, especially if the observed inspection fraction defective is very low.

Table 8.11, which is included only for illustrative purposes, shows that no statistical tests on inspection accuracy are possible for inspection sample sizes of 100 and the following hypotheses.

H_o: $\mu_o(ADR) = .90$

H_1: $\mu_1(ADR) = .75$.

Table 8.14 shows that with an inspection sample size of 5000 and observed fraction defective of .010 no test is possible for the above hypotheses. However, higher inspection observed fraction defective will allow for adequate audit inspection to determine inspection accuracy.

TABLE 8.1

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.50, INSPECTION SAMPLE SIZE = 100

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.040	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.050	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.060	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.080	74	3	LOT SIZE TOO SMALL	
0.100	53	3	LOT SIZE TOO SMALL	
0.120	41	3	LOT SIZE TOO SMALL	
0.140	33	3	LOT SIZE TOO SMALL	
0.160	27	3	LOT SIZE TOO SMALL	
0.180	23	3	LOT SIZE TOO SMALL	
0.200	19	3	LOT SIZE TOO SMALL	
0.250	13	2	72	6
0.300	10	2	51	5
0.350	7	2	38	5
0.400	5	2	28	5
0.450	4	2	21	4
0.500	2	2	16	4

TABLE 8.2

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.50, INSPECTION SAMPLE SIZE = 500

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	293	3	LOT SIZE TOO SMALL	
0.030	175	3	LOT SIZE TOO SMALL	
0.040	123	3	LOT SIZE TOO SMALL	
0.050	95	3	456	6
0.060	76	3	354	5
0.080	54	3	241	5
0.100	41	3	180	5
0.120	33	3	141	5
0.140	27	2	115	5
0.160	23	2	96	5
0.180	19	2	82	5
0.200	17	2	71	4
0.250	12	2	51	4
0.300	9	2	37	4
0.350	7	2	28	4
0.400	5	2	21	4
0.450	3	2	16	4
0.500	2	2	12	3

TABLE 8.3

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.50, INSPECTION SAMPLE SIZE = 1000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	592	3	LOT SIZE TOO SMALL	
0.020	253	3	LOT SIZE TOO SMALL	
0.030	159	3	732	5
0.040	115	3	506	5
0.050	90	3	384	5
0.060	73	3	307	5
0.080	52	3	217	5
0.100	40	2	165	5
0.120	32	2	132	5
0.140	27	2	109	4
0.160	22	2	91	4
0.180	19	2	78	4
0.200	17	2	67	4
0.250	12	2	49	4
0.300	9	2	36	4
0.350	6	2	27	4
0.400	5	2	21	4
0.450	3	2	16	4
0.500	2	2	12	3

TABLE 8.4

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.50, INSPECTION SAMPLE SIZE = 5000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL).

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	474	3	2017	5
0.020	228	3	924	5
0.030	148	3	594	5
0.040	109	3	434	5
0.050	86	3	340	4
0.060	70	3	278	4
0.080	51	2	201	4
0.100	39	2	156	4
0.120	32	2	125	4
0.140	26	2	104	4
0.160	22	2	88	4
0.180	19	2	75	4
0.200	16	2	65	4
0.250	12	2	47	4
0.300	9	2	35	4
0.350	6	2	27	4
0.400	5	2	20	4
0.450	3	2	15	3
0.500	2	2	11	3

TABLE 8.5

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.50, INSPECTION SAMPLE SIZE = 10000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	462	3	1873	5
0.020	225	3	892	5
0.030	147	3	580	5
0.040	108	3	426	4
0.050	85	3	335	4
0.060	70	3	275	4
0.080	51	2	199	4
0.100	39	2	154	4
0.120	32	2	124	4
0.140	26	2	103	4
0.160	22	2	87	4
0.180	19	2	75	4
0.200	16	2	65	4
0.250	12	2	47	4
0.300	9	2	35	4
0.350	6	2	27	4
0.400	5	2	20	4
0.450	3	2	15	3
0.500	2	2	11	3

TABLE 8.6

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.60, INSPECTION SAMPLE SIZE = 100

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1		CASE 2	
	AUDIT SAMPLE SIZE	AUDIT DEFECTIVES	AUDIT SAMPLE SIZE	AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.040	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.050	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.060	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.080	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.100	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.120	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.140	80	4	LOT SIZE TOO SMALL	
0.160	65	4	LOT SIZE TOO SMALL	
0.180	54	4	LOT SIZE TOO SMALL	
0.200	46	4	LOT SIZE TOO SMALL	
0.250	32	4	LOT SIZE TOO SMALL	
0.300	23	4	LOT SIZE TOO SMALL	
0.350	17	3	LOT SIZE TOO SMALL	
0.400	13	3	49	7
0.450	10	3	38	7
0.500	7	3	29	6

TABLE 8.7

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.60, INSPECTION SAMPLE SIZE = 500

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	411	4	LOT SIZE TOO SMALL	
0.040	281	4	LOT SIZE TOO SMALL	
0.050	212	4	LOT SIZE TOO SMALL	
0.060	169	4	LOT SIZE TOO SMALL	
0.080	119	4	388	7
0.100	90	4	287	7
0.120	72	4	225	7
0.140	59	4	183	6
0.160	50	4	153	6
0.180	42	3	130	6
0.200	37	4	112	6
0.250	26	3	80	6
0.300	20	3	60	6
0.350	15	3	46	6
0.400	11	3	35	5
0.450	8	3	27	5
0.500	6	3	21	5

TABLE 8.8

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.60, INSPECTION SAMPLE SIZE = 1000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	575	4	LOT SIZE TOO SMALL	
0.030	351	4	LOT SIZE TOO SMALL	
0.040	251	4	811	7
0.050	194	4	610	7
0.060	157	4	486	7
0.080	112	4	341	6
0.100	86	4	259	6
0.120	69	4	207	6
0.140	57	4	170	6
0.160	48	3	143	6
0.180	41	3	122	6
0.200	36	3	106	6
0.250	26	3	77	6
0.300	19	3	58	6
0.350	15	3	44	5
0.400	11	3	34	5
0.450	8	3	26	5
0.500	6	3	20	5

TABLE 8.9

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.60, INSPECTION SAMPLE SIZE = 5000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	1022	4	3190	7
0.020	484	4	1437	6
0.030	314	4	918	6
0.040	231	4	670	6
0.050	181	4	524	6
0.060	148	4	429	6
0.080	108	4	310	6
0.100	83	4	240	6
0.120	67	3	194	6
0.140	56	3	161	6
0.160	47	3	136	6
0.180	40	3	117	6
0.200	35	3	102	6
0.250	25	3	74	6
0.300	19	3	56	5
0.350	14	3	43	5
0.400	11	3	33	5
0.450	8	3	25	5
0.500	6	3	19	5

TABLE 8.10

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.60, INSPECTION SAMPLE SIZE = 10000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	981	4	2909	6
0.020	474	4	1375	6
0.030	310	4	892	6
0.040	228	4	656	6
0.050	180	4	515	6
0.060	147	4	422	6
0.080	107	4	307	6
0.100	83	3	238	6
0.120	67	3	192	6
0.140	56	3	160	6
0.160	47	3	135	6
0.180	40	3	116	6
0.200	35	3	101	6
0.250	25	3	74	6
0.300	19	3	56	5
0.350	14	3	43	5
0.400	11	3	33	5
0.450	8	3	25	5
0.500	6	3	19	5

TABLE 8.11

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.75, INSPECTION SAMPLE SIZE = 100

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.040	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.050	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.060	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.080	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.100	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.120	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.140	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.160	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.180	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.200	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.250	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.300	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.350	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.400	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.450	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.500	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	

TABLE 8.12

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.75, INSPECTION SAMPLE SIZE = 500

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.040	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.050	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.060	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.080	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.100	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.120	372	11	LOT SIZE TOO SMALL	
0.140	301	10	LOT SIZE TOO SMALL	
0.160	251	10	LOT SIZE TOO SMALL	
0.180	213	10	LOT SIZE TOO SMALL	
0.200	183	10	378	15
0.250	132	9	270	15
0.300	99	9	201	14
0.350	76	9	155	14
0.400	59	9	121	13
0.450	46	8	95	13
0.500	36	8	74	12

TABLE 8.13

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.75, INSPECTION SAMPLE SIZE = 1000

ALPHA ERROR =. BETA ERROR =0.050 (NORMAL)
ALPHA ERROR =. BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.030	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.040	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.050	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.060	795	11	LOT SIZE TOO SMALL	
0.080	554	10	LOT SIZE TOO SMALL	
0.100	419	10	851	15
0.120	334	10	670	15
0.140	274	9	547	14
0.160	231	9	458	14
0.180	198	9	391	14
0.200	171	9	338	14
0.250	125	9	246	13
0.300	94	9	186	13
0.350	73	9	144	13
0.400	57	8	112	12
0.450	44	8	88	12
0.500	34	8	69	12

TABLE 8.14

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.75, INSPECTION SAMPLE SIZE = 5000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	LOT SIZE TOO SMALL		LOT SIZE TOO SMALL	
0.020	2307	10	4634	15
0.030	1465	10	2879	14
0.040	1066	9	2074	14
0.050	834	9	1612	14
0.060	681	9	1312	14
0.080	493	9	946	13
0.100	382	9	731	13
0.120	308	9	590	13
0.140	256	9	490	13
0.160	217	9	415	13
0.180	187	9	358	13
0.200	163	9	312	13
0.250	119	9	229	13
0.300	91	8	175	12
0.350	70	8	136	12
0.400	55	8	107	12
0.450	43	8	84	12
0.500	33	7	66	11

TABLE 8.15

AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES TO REJECT ACCURACY =0.90 AND ACCEPT ACCURACY =0.75, INSPECTION SAMPLE SIZE = 10000

ALPHA ERROR = BETA ERROR =0.050 (NORMAL)
ALPHA ERROR = BETA ERROR =0.082 (CAMP MEIDEL)

OBSERVED INSPECTION FRACTION DEFECTIVE	CASE 1 AUDIT SAMPLE SIZE	CASE 1 AUDIT DEFECTIVES	CASE 2 AUDIT SAMPLE SIZE	CASE 2 AUDIT DEFECTIVES
0.010	4666	10	9364	15
0.020	2185	9	4243	14
0.030	1414	9	2719	14
0.040	1038	9	1988	14
0.050	816	9	1558	13
0.060	669	9	1275	13
0.080	486	9	926	13
0.100	378	9	719	13
0.120	305	9	581	13
0.140	254	9	483	13
0.160	216	9	410	13
0.180	186	9	354	13
0.200	162	9	309	13
0.250	119	9	227	13
0.300	90	8	173	12
0.350	70	8	135	12
0.400	55	8	106	12
0.450	43	8	83	11
0.500	33	7	66	11

CHAPTER IX

CONCLUSION

Five possible measures of inspection accuracy were investigated: the ratio of correct inspections, a utility theory approach, the ratio of good product accepted, the ratio of defective product rejected, and the accuracy of product improvement. The advantages and disadvantages of each measure have been reviewed.

Based on current methods of data collection by industrial inspection departments and their application in the studies found in the literature, the ratio of defective product rejected was selected as the measure that should be further examined. The ratio of defective product rejected is determined by dividing the total number of defectives found by the inspector by the total number of defectives in the lot. During the actual production process the only way to determine the total number of defectives in the lot is by an audit reinspection of the lot to determine how many defectives were missed by the original inspector.

Two types of sampling plans were derived. Single-hypothesis plans determine whether an acceptable inspection accuracy is not being met, based on the number of defectives

found during the audit inspection. Double-hypothesis plans determine whether a preselected acceptable inspection accuracy level or a preselected unacceptable inspection accuracy level is being attained. The double sampling plans require that the audit sample size as well as the number of audit defectives be stated in the sampling plan.

The sampling plans are affected by a major assumption regarding the accuracy of the audit inspector. Two cases are explored, one where the audit inspector is 100 percent accurate and the other where the audit inspector accuracy is equal to that of the initial inspector.

A study of the sampling plans reveals that large lot sizes are generally required if an adequate measure of inspector accuracy is to be determined. As the observed inspection defect rate goes down, the lot size requirements become fairly large. The audit sample size also must be fairly large with respect to the original lot size as the observed inspection defect rate goes down. For example, in a double-hypothesis test with the acceptable accuracy of .90 and an unacceptable accuracy of .50, for an observed inspection fraction defective of .01 the inspection sample size should be 1000. Table 8.3 also shows that the audit sample size should be 592 if a 100 percent accurate audit inspector is assumed. For the case where the audit inspector has the same accuracy as the initial inspector an even larger inspection sample size would be required.

An effective tool for determining inspector accuracy has been developed for use by industry. The sampling plans result in estimates of inspector accuracy which can be used to determine the actual manufacturing quality level and the actual outgoing quality level. Good estimates of the outgoing quality level are required to determine future warranty and customer liability costs.

Examples of the two types of sampling plans have been included in the dissertation. Computer programs have been included in the Appendix which can be modified to meet any user's specific needs.

APPENDIX

```
C     THIS PROGRAM CALCULATES ACCURACY EXPECTED VALUES FOR VARIOUS
C     INSPECTION AND REINSPECTION TEST RESULTS. THE DATA CARD INCLUDES
C     THE FOLLOWING INFORMATION AND CAN BE MODIFIED FOR OTHER VALUES.
C     NI IS THE INSPECTION SAMPLE SIZE, NNI IS AN INDEX NUMBER FOR NI IF
C     MORE THAN ONE VALUE IS USED------PI IS THE INSPECTION FRACTION
C     DEFECTIVE, NPI IS ITS ASSOCIATED INDEX NUMBER------NRFAC IS A
C     FACTOR TO DETERMINE THE AUDIT SAMPLE SIZE AND IS DIVIDED INTO NI,
C     NNR IS ITS ASSOCIATED INDEX NUMBER.
C
      REAL NI(2),PI(4),NRFAC(5),NR,MQL1,MQL2
      DATA NI/1.0E2,1.0E3/,PI/.01,  .05,.10,.25/,NRFAC/1.0,2.0,5.0,10.0,
     1100.0/,NNI/2/,NPI/4/,NNR/5/
      ITAB =-1
      DO 100  INI = 1,NNI
      DO 100  IPI = 1,NPI
      KOUNT =0
      KONTIN=0
      ITAB=ITAB+1
      JNI = NI(INI)
      WRITE(6,530)ITAB
      WRITE(6,500)JNI,PI(IPI)
      WRITE(6,505)
      DO 100  INR=1,NNR
      IF(INR.NE.1) GO TO 130
      NR=NI(INI)*(1.0-PI(IPI))
      GO TO 140
  130 NR=NI(INI)/NRFAC(INR)
      WRITE (6,560)
       KOUNT=KOUNT + 1
  140 IF(NI(INI)*(1.0-PI(IPI)).LT.NR) GO TO 110
      SADR=1.0
      DR=0
  160 IF(DR.GE.10) GO TO 200
      DR=DR+1
      GO TO 220
  200 IF(DR.GE.50) GO TO 210
```

```
      DR=DR+5
      GO TO 220
  210 DR=DR+10
  220 PR=DR/NR
      JDR = DR
      JNR = NR
      IF(PR.GT.1.0) GO TO 110
      T1=(1.0-PI(IPI))*PR
      T2= PI(IPI)+T1
      T3= PI(IPI)-T1
      RAD=SQRT((1.0/(NI(INI)*PI(IPI)*(1.0-PI(IPI))))+(1.0-PR)/(NR*PR))
      ADR 1 =PI(IPI)/T2
      IF(DR.LE.1.0) GO TO 150
      IF(SADR-ADR 1 .LT.0.01) GO TO 160
      IF(ADR 1 .GT..90) GO TO 150
      IF(SADR-ADR 1 .LT.0.05)GO TO 140
  150 SADR =ADR 1
      IF(ADR 1 .LT.0.25) GO TO 110
      KOUNT=KOUNT+1
      IF(KONTIN.EQ.0.AND.KOUNT.LT.27) GO TO 180
      IF(KONTIN.GT.0.AND.KOUNT.LT.31) GO TO 180
      WRITE(6,540) ITAB
      WRITE(6,505)
      KONTIN=KONTIN+1
      KOUNT = 0
  180 ADR 2 =T3/PI(IPI)
      SIG1      =((PI(IPI)*T1)/(T2*T2))*RAD
      MQL1=1.0-T2
      OQL1=1.0-(NI(INI)*T1-DR)/(NI(INI)*(1.0-PI(IPI))-DR)
      KADR2=1000*ADR 2
      KPI=1000*PI(IPI)+1
      IF(KADR2.LE.KPI) GO TO 170
      SIG2      =(T1/PI(IPI))*RAD
      MQL2=1.0-PI(IPI)-T1/ADR 2
      OQL2=1.0-(NI(INI)*T1-DR*ADR 2)/((NI(INI)*(1.0-PI(IPI))-DR)*ADR 2)
      WRITE(6,510)JNR,PR ,ADR 1,SIG1,MQL1,OQL1,ADR 2,SIG2,MQL2,OQL2
```

```
      GO TO 160
  170 WRITE(6,520)JNR,PR ,ADR 1,SIG1,MQL1,OQL1
      GO TO 160
  500 FORMAT(20X,'EXAMPLES OF ACCURACY EXPECTED VALUES OBTAINED FROM DIF
     1FERENT INSPECTION AND',/,29X,
     2'REINSPECTION TEST RESULTS, INSPECTION SAMPLE SIZE =',I5,',',
     3/,37X,'INSPECTION FRACTION DEFECTIVE =',F5.2,/)
  505 FORMAT(10X,'AUDIT',2X,'AUDIT',7X,'- - - - - -  CASE 1  - - - - - -
     1',6X,'- - - - - -  CASE 2  - - - - - -',/,10X,'SAMPLE FRACTION',/,
     210X,'SIZE   DEFECTIVE  ACCURACY  STD.DEV.  MQL       OQL',6X,
     3'ACCURACY  STD.DEV.  MQL       OQL',/)
  510 FORMAT(10X,I5,F9.4 ,2X,4F9.4,2X,4F9.4)
  520 FORMAT(10X,I5,F9.4 ,2X,4F9.4,13X,'INVALID FOR CASE 2')
  530 FORMAT(1H1,//////,50X,'TABLE 5.',I1,/)
  540 FORMAT(1H1,//////,45X,'TABLE 5.',I1,' CONTINUED',/)
  560 FORMAT(1X,'    ')
  110 CONTINUE
  100 CONTINUE
      STOP
      END
```

```
C     THIS PROGRAM DETERMINES THE MINIMUM NUMBER OF DEFECTIVES TO BE
C     FOUND BY THE AUDITOR TO REJECT A SPECIFIED VALUE OF INSPECTION
C     ACCURACY.    THIS IS A SINGLE HYPOTHESIS TEST.      THE DATA CARD
C     INCLUDES THE FOLLOWING INFORMATION AND CAN BE MODIFIED FOR OTHER
C     VALUES.
C     NI IS THE INSPECTION SAMPLE SIZE, NNI IS AN INDEX NUMBER FOR NI IF
C     MORE THAN ONE VALUE IS USED------PI IS THE INSPECTION FRACTION
C     DEFECTIVE, NPI IS ITS ASSOCIATED INDEX NUMBER------NRFAC IS A
C     FACTOR TO DETERMINE THE AUDIT SAMPLE SIZE AND IS DIVIDED INTO NI,
C     NNR IS ITS ASSOCIATED INDEX NUMBER.
C     ALNORM IS THE ALPHA ERROR DESIRED ASSUMING A NORMAL DISTRIBUTION
C      AND CONST IS THE ASSOCIATED NORMALIZED Z STATISTIC.
C
      DIMENSION NI(4),PI(19),NRFAC(4)
      INTEGER    DR175,DR190,DR275,D'290
      DATA NI/500,1000,5000,10000/
      DATA PI/.01,.02,.03,.04,.05,.06,.08,.10,.12,.14,.16,.18,.20,.25,.3
     10,.35,.40,.45,.50/
      DATA NRFAC/2,5,10,50/
      DATA NNI/4/,NPI/19/,NNR/4/,CONST/1.645/,ALNORM/.05/
      ITAB=0
      DO 610 INI = 1,NNI
      DO 610 INR = 1,NNR
  130 NR=NI(INI)/NRFAC(INR)
      ITAB=ITAB+1
      IF(ITAB.LT.10) WRITE (6,910)ITAB
      IF(ITAB.GE.10) WRITE (6,920)ITAB
      ALCAMP=1.0/(2.25*CONST**2)/2.0
      WRITE(6,810) NI(INI),NR,ALNORM,ALCAMP
      DO 610 IPI = 1,NPI
      NRUN =1
  110 IF(IPI.EQ.1) DR=1
      IF(NRUN.EQ.1.AND.IPI.NE.1)DR=D'190
      IF(NRUN.EQ.2.AND.IPI.NE.1)DR=D'175
      IF(NRUN.EQ.3.AND.IPI.NE.1)DR=D'290
      IF(NRUN.EQ.4.AND.IPI.NE.1)DR=D'275
```

```
      IF(DR.LT.0) DR=1
      IF(NI(INI).LE.1000.0) DR=1
      GO TO 250
  120 DR = DR+1
  250 IF(NI(INI)*(1.0-PI(IPI)).LT.NR) GO TO 600
      ANR=NR
      PRA= DR/NR
      T1A=(1-PI(IPI))*PRA
      T2A=PI(IPI)+T1A
      T3A=PI(IPI)-T1A
      ADR 1 A= PI(IPI)/T2A
      ADR 2 A= T3A/PI(IPI)
      RADA= SQRT((1.0/(NI(INI)*PI(IPI)*(1-PI(IPI))))+(1-PRA)/(NR*PRA))
      SIG 1 A=((PI(IPI)*T1A)/(T2A*T2A))*RADA
      SIG 2 A=(T1A/PI(IPI))*RADA
      IF(NRUN.EQ.1) GO TO 140
      IF(NRUN.EQ.2) GO TO 100
      IF(NRUN.EQ.3) GO TO 160
      IF(NRUN.EQ.4) GO TO 150
  100 IF(DR.GT.NR) GO TO  170
      IF(ADR 1 A+CONST*SIG 1 A.LT..75) GO TO 180
      GO TO 120
  170 DR175=-1
      NRUN = NRUN +1
      GO TO 110
  180 DR175=DR
      NRUN = NRUN +1
      GO TO 110
  140 IF(DR.GT.NR) GO TO 190
      IF(ADR 1 A+CONST*SIG 1 A.LT..90) GO TO 200
      GO TO 120
  190 DR190=-1
      NRUN = NRUN +1
      GO TO 110
  200 DR190=DR
      NRUN = NRUN +1
```

```
      GO TO 110
  160 IF(DR.GT.NR) GO TO 230
      IF(ADR 2 A+CONST*SIG 2 A.LT..90) GO TO 240
      GO TO 120
  230 DR290=-1
      NRUN = NRUN +1
      GO TO 110
  240 DR290=DR
      NRUN = NRUN +1
      GO TO 110
  150 IF(DR.GT.NR) GO TO 210
      IF(ADR 2 A+CONST*SIG 2 A.LT..75) GO TO 220
      GO TO 120
  210 DR275=-1
      GO TO 580
  220 DR275=DR
  580 IF(DR190.LT.0.AND.DR290.LT.0) WRITE(6,820) PI(IPI)
      IF(DR175.LT.0.AND.DR190.GT.0.AND.DR290.LT.0) WRITE(6,830) PI(IPI),
     1   DR190
      IF(DR175.GT.0.AND.DR190.GT.0.AND.DR290.LT.0) WRITE(6,840) PI(IPI)
     1,   DR175,DR190
      IF(DR190.LT.0.AND.DR275.LT.0.AND.DR290.GT.0) WRITE(6,850) PI(IPI),
     1   DR290
      IF(DR190.LT.0.AND.DR275.GT.0.AND.DR290.GT.0) WRITE(6,850) PI(IPI),
     1NR,DR275,DR290
      IF(DR175.LT.0.AND.DR190.GT.0.AND.DR275.LT.0.AND.DR290.GT.0) WRITE
     1(6,870) PI(IPI),   DR190,DR290
      IF(DR175.GT.0.AND.DR190.GT.0.AND.DR275.LT.0.AND.DR290.GT.0) WRITE
     1(6,880) PI(IPI),   DR175,DR190,DR290
      IF(DR175.LT.0.AND.DR190.GT.0.AND.DR275.GT.0.AND.DR290.GT.0) WRITE
     1(6,890) PI(IPI),   DR190,DR275,DR290
      IF(DR175.GT.0.AND.DR190.GT.0.AND.DR275.GT.0.AND.DR290.GT.0)
     1WRITE(6,900) PI(IPI)   ,DR175,DR190,DR275,DR290
  810 FORMAT(17X,'MINIMUM NUMBER OF DEFECTIVE ITEMS FOUND BY THE',/,
     116X,'AUDITOR TO REJECT SPECIFIED INSPECTION ACCURACY,',/,
     225X,'INSPECTION SAMPLE SIZE =',I5,',',/,
```

```
     328X,'AJDIT SAMPLE SIZE =',I4,///,
     415X,'ALPHA ERROR =',F5.3,2X,'(NORMAL)',/,
     515X,'ALPHA ERROR =',F5.3,2X,'(CAMP MEIDEL)',//,
     615X,'OBSERVED',13X,'CASE 1',19X,'CASE 2',/,15X,'INSPECTION',/,
     715X,'FRACTION',7X,'ACCURACY',2X,'ACCURACY',7X,'ACCURACY',2X,
     8'ACCURACY ',/,
     915X,'DEFECTIVE',8X,'=0.75',5X,'=0.90',10X,'=0.75',5X,'=0.90',/)
  820 FORMAT(17X,F5.3,8X,'NO TEST',3X,'NO TEST',8X,'NO TEST',3X,
     1'NO TEST',/)
  830 FORMAT(17X,F5.3,8X,'NO TEST',3X,I7,8X,'NO TEST',3X,'NO TEST',/)
  840 FORMAT(17X,F5.3,8X,I7,3X,I7,8X,'NO TEST',3X,'NO TEST',/)
  850 FORMAT(17X,F5.3,8X,'NO TEST',3X,'NO TEST',8X,'NO TEST',3X,I7,/)
  860 FORMAT(17X,F5.3,8X,'NO TEST',3X,'NO TEST',8X,I7,3X,I7,/)
  870 FORMAT(17X,F5.3,8X,'NO TEST',3X,I7,8X,'NO TEST',3X,I7,/)
  880 FORMAT(17X,F5.3,8X,I7,3X,I7,8X,'NO TEST',3X,I7,/)
  890 FORMAT(17X,F5.3,8X,'NO TEST',3X,I7,8X,I7,3X,I7,/)
  900 FORMAT(17X,F5.3,8X,I7,3X,I7,8X,I7,3X,I7,/)
  910 FORMAT (1H1,////,35X,'TABLE 7.',I1,/)
  920 FORMAT (1H1,////,35X,'TABLE 7.',I2,/)
  600 CONTINUE
  610 CONTINUE
      STOP
      END
```

```
C      THIS PROGRAM DETERMINES AUDIT SAMPLE SIZES AND THE MINIMUM NUMBER
C      OF DEFECTIVES NECESSARY TO REJECT THE NULL HYPOTHESIS FOR A
C      DOUBLE HYPOTHESIS TEST ON INSPECTION ACCURACY.   THE NULL
C      HYPOTHESIS IS EQUAL TO AN ACCEPTABLE VALUE OF INSPECTION ACCURACY.
C      THE ALTERNATE HYPOTHESIS IS EQUAL TO AN UNACCEPTABLE VALUE OF
C      INSPECTION ACCURACY.   THE DATA CARD INCLUDES THE FOLLOWING
C      INFORMATION AND CAN BE MODIFIED FOR OTHER VALUES.
C      NI IS THE INSPECTION SAMPLE SIZE, NNI IS AN INDEX NUMBER FOR NI IF
C      MORE THAN ONE VALUE IS USED------PI IS THE INSPECTION FRACTION
C      DEFECTIVE, NPI IS ITS ASSOCIATED INDEX NUMBER.
C      ADRAC IS THE VALUE OF ACCEPTABLE INSPECTION ACCURACY.
C      ADRUN ARE THE VALUES OF UNACCEPTABLE INSPECTION ACCURACY, NUN
C      IS ITS INDEX NUMBER.
C      ALNORM IS THE ALPHA ERROR DESIRED ASSUMING A NORMAL DISTRIBUTION
C       AND CONST IS THE ASSOCIATED NORMALIZED Z STATISTIC.
C
      DIMENSION NI(5),PI(19),ADRU(3)
      DATA NI/100,500,1000,5000,10000      /,PI/.01,.02,.03,.04,.05,.06,
     1.08,.10,.12,.14,.16,.18,.20,.25,.30,.35,.40,.45,.50/,NNI/5/,NPI/19
     2/,CONST/1.645/,ALNORM/.05/,ADRU/.50,.60,.75/,ADRAC/.90/,NUN/3/
  500 FORMAT(19X,F5.3,8X,I6  ,5X,I6  ,5X,I6  ,5X,I6,/)
  510 FORMAT(19X,F5.3,8X,'LOT SIZE TOO SMALL',4X,'LOT SIZE TOO SMALL',/)
  520 FORMAT(19X,F5.3,8X,'LOT SIZE TOO SMALL',4X,I6  ,5X,I6  ,/)
  530 FORMAT(19X,F5.3,8X,I6  ,5X,I6  ,5X,'LOT SIZE TOO SMALL',/)
  540 FORMAT(   19X,'AUDIT SAMPLE SIZE AND MINIMUM NUMBER OF DEFECTIVES
     1TO',/,22X,'REJECT ACCURACY =',F4.2,1X,'AND ACCEPT ACCURACY =',
     2F4.2,'',/,30X,'INSPECTION SAMPLE SIZE =',I6,///,17X,
     3'ALPHA ERROR = BETA ERROR =',F5.3,2X,'(NORMAL)',/,17X,'ALPHA ERROR
     4 = BETA ERROR =',F5.3,2X,'(CAMP MEIDEL)',//,
     517X,'OBSERVED',12X,
     6'CASE 1',16X,'CASE 2', /,17X,'INSPECTION',5X,'AUDIT',6X,'AUDIT',
     7       6X,'AUDIT',7X,'AUDIT',/,17X,'FRACTION',7X,'SAMPLE',3X,'DEFE
     8CTIVES',3X,'SAMPLE',4X,'DEFECTIVES',/,17X,'DEFECTIVE',6X,'SIZE',18
     9X,'SIZE',/)
  550 FORMAT(1H1,////,40X,'TABLE 8.',I1,/)
  560 FORMAT(1H1,////,40X,'TABLE 8.',I2,/)
```

```
      ALCAMP=1.0/(2.25*CONST**2)/2.0
      ITAB=0
      DO 610 IUN=1,NUN
      ADRUN=ADRU(IUN)
      DO 610 INI = 1,NNI
      ITAB=ITAB+1
      IF(ITAB.LT.10) WRITE(6,550) ITAB
      IF(ITAB.GE.10) WRITE(6,560) ITAB
      WRITE(6,540) ADRAC,ADRUN,NI(INI),ALNORM,ALCAMP
      DO 610 IPI = 1,NPI
      NRUN = 0
  100 NRUN = NRUN + 1
      IF(NRUN.EQ.3) GO TO 600
      NR=0
  110 NR=NR+1
      DEC =(ADRAC  -ADRUN  )/CONST
      IF(NRUN.EQ.2) GO TO 120
      IF(NR.GT.NI(INI)*(1-PI(IPI))) GO TO 130
      PRUN  = (PI(IPI)*(1-ADRUN  ))/(ADRUN  *(1-PI(IPI)))
      PRAC  = (PI(IPI)*(1-ADRAC  ))/(ADRAC  *(1-PI(IPI)))
      SIGUN  =((PRUN  *PI(IPI)*(1-PI(IPI)))/ ((PI(IPI)+PRUN  *(1-PI(IPI)
     1))**2))*SQRT(  1/(NI(INI)*PI(IPI)*(1-PI(IPI)))+(1-PRUN)/(NR*PRUN))
      SIGAC  =((PRAC  *PI(IPI)*(1-PI(IPI)))/ ((PI(IPI)+PRAC  *(1-PI(IPI)
     1))**2))*SQRT(  1/(NI(INI)*PI(IPI)*(1-PI(IPI)))+(1-PRAC)/(NR*PRAC))
      IF(SIGUN  +SIGAC  .GT.DEC) GO TO 110
      NRDEC=NR
      DR1=NRDEC*PI(IPI)*(1.0-ADRAC+CONST*SIGAC)/((ADRAC-CONST*SIGAC)*
     1(1.0-PI(IPI))) +1.0
      IDR1=DR1
      GO TO 100
  120 IF(NR.GT.NI(INI)*(1-PI(IPI))) GO TO 140
      PRUN  =(PI(IPI)*(1-ADRUN  ))/(1-PI(IPI))
      PRAC  =(PI(IPI)*(1-ADRAC  ))/(1-PI(IPI))
      SIGUN  =(PRUN  *(1-PI(IPI))/PI(IPI))*SQRT(1/(NI(INI)*PI(IPI)*(1-PI
     1(IPI)))+(1-PRUN  )/(NR*PRUN ))
      SIGAC  =(PRAC  *(1-PI(IPI))/PI(IPI))*SQRT(1/(NI(INI)*PI(IPI)*(1-PI
```

```
   1(IPI)))+(1-PRAC  )/(NR*PRAC ))
     IF(SIGUN  +SIGAC  .GT.DEC) GO TO 110
     NRDECB=NR
     DR2=NRDECB*PI(IPI)*(1.0+CONST*SIGAC-ADRAC)/(1.0-PI(IPI))+1.0
     IDR2=DR2
     GO TO  430
130  NRDEC=-10
     GO TO 100
140  NRDECB=-20
430  IF(NRDEC.LT.0.0.AND.NRDECB.LT.0.0) GO TO 400
     IF(NRDEC.LT.0.0.AND.NRDECB.GT.0.0) GO TO 410
     IF(NRDEC.GT.0.0.AND.NRDECB.LT.0.0) GO TO 420
     WRITE(6,500)PI(IPI),NRDEC,IDR1 ,NRDECB,IDR2
     GO TO 600
400  WRITE(6,510) PI(IPI)
     GO TO 600
410  WRITE(6,520) PI(IPI),NRDECB,IDR2
     GO TO 600
420  WRITE(6,530) PI(IPI),NRDEC,IDR1
600  CONTINUE
610  CONTINUE
     STOP
     END
```

REFERENCES

Periodicals

1. Ayers, A. W., "A Comparison of Certain Visual Factors with the Efficiency of Textile Inspectors," Journal of Applied Psychology, Vol. 26, No. 6, Dec. 1942, pp. 812-827.

2. Belbin, R. M., "New Fields for Quality Control," Metal Industry, Vol. 90, No. 4, Jan. 1957, pp. 63-65.

3. Blais, R. A., "True Reliability Versus Inspection Efficiency," IEEE Transactions on Reliability, Vol. R-18, No. 4, Nov. 1969, pp. 201-203.

4. Forster-Cooper, J., "A Description of the Statistical Quality Control System in Operation at Joseph Lucas (Electrical) LTD," Engineering Inspection, Vol. 18, No. 2, Feb. 1954, pp. 110-121.

5. Harris, D. H., "Effect of Defect Rate on Inspection Accuracy," Journal of Applied Psychology, Vol. 52, No. 5, Oct. 1968, pp. 377-379.

6. Harris, D. H., "Effect of Equipment Complexity on Inspection Performance," Journal of Applied Psychology, Vol. 50, No. 3, June 1966, pp. 236-237.

7. Hayes, A. S., "Control of Visual Inspection," Industrial Quality Control, Vol. 6, No. 6, May 1950, pp. 73-76.

8. Jacobson, H. J., "A Study of Inspector Accuracy," Industrial Quality Control, Vol. 9, No. 2, Sept. 1952, pp. 16-25.

9. Juran, J. M., "Inspectors Errors in Quality Control," Mechanical Engineering, Vol. 57, No. 10, Oct. 1935, pp. 643-644.

10. Lawsche, C. H., and Tiffin, J., "The Accuracy of Precision Instrument Measurement in Industrial Inspection," Journal of Applied Psychology, Vol. 29, No. 6, Dec. 1945, pp. 413-419.

11. Mackworth, N. H., "Work Design and Training for Future Industrial Skills," Institute of Production Engineers Journal, Vol. 35, No. 4, April 1956, pp. 214-228.

12. Marash, S. A., "Performing Quality Audits," Industrial Quality Control, Vol. 22, No. 7, Jan. 1966, pp. 342-347.

13. Marien, L. P., "Inspecting the Inspector," American Machinist, Vol. 74, No. 22, May 1931, pp. 815-817.

14. McKenzie, R. M., "On the Accuracy of Inspectors," Ergonomics, Vol. 1, No. 3, May 1958, pp. 258-272.

15. Purcell, W. R., "Sampling Techniques in Quality System Audits," Quality Progress, Vol. 1, No. 10, Oct. 1968, pp. 13-15.

16. Schwartz, D. H., "Statistical Sleuthing to Detect Bias in Visual Inspection," Industrial Quality Control, Vol. 3, No. 6, May 1947, pp. 14-17.

17. Tiffin, J., and Rogers, H. B., "The Selection and Training of Inspectors," Personnel, Vol. 18, No. 1, July 1941, pp. 14-31.

Books

18. Burr, I. W., Engineering Statistics and Quality Control, McGraw-Hill, New York, 1953.

19. Duncan, A. J., Quality Control and Industrial Statistics, 3rd Edition, Richard D. Irwin, Homewood, Ill., 1965.

20. Feigenbaum, A. V., Total Quality Control, McGraw-Hill, New York, 1961.

21. Grant, E. L., Statistical Quality Control, 3rd Edition, McGraw-Hill, New York, 1964.

22. Juran, J. M., Ed., Quality Control Handbook, McGraw-Hill, New York, 1951.

23. Juran, J. M., and Gryna, F. M., Quality Planning and Analysis, McGraw-Hill, New York, 1970.

24. Kelly, M. L., A Study of Industrial Inspection by the Method of Paired Comparisons, Psychological Monographs, No. 394, American Psychological Association, Washington, D. C., 1955.

25. Kendall, M. G., and Stuart, A., Advanced Theory of Statistics, Vol. 1, Hafner, New York, 1963.

26. Kennedy, W., Inspection and Gaging, The Industrial Press, New York, 1957.

27. Shewhart, W. A., Economic Control of Quality of Manufactured Product, D. Van Nostrand, New York, 1931.

Transactions and Proceedings

28. Kidwell, J. L., Squeglia, N. L., and Lavender, H. J., "Escape Probability as a Design Consideration," Annual Technical Conference Transactions, American Society for Quality Control, 1965, pp. 486-499.

BIOGRAPHICAL SKETCH

Lee Allen Weaver was born April 28, 1935, at Hellertown, Pennsylvania. In June, 1953, he was graduated from Allentown High School, Allentown, Pennsylvania. In June, 1957, he received the degree of Bachelor of Arts from Moravian College. In September, 1957, he enrolled in the graduate school of the University of Florida. He worked as a graduate assistant in the Department of Mathematics until June, 1959, when he received the Master of Science. From 1960 until 1967 he worked as a Product Assurance engineer for Honeywell Inc. In 1967 he joined the faculty of the University of South Florida. From June, 1968, until the present time he has pursued his work toward the degree of Doctor of Philosophy.

Lee Allen Weaver is married to the former LaRae Kathryn Fritzinger and is the father of four children. He is a member of the American Society for Quality Control, and the Institute of Electronic and Electrical Engineers. He is a statistical consultant to a Working Group of the International Electrotechnical Commission and to the Director of Product Assurance of Honeywell Inc.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Warren Menke, Chairman
Associate Professor of Management

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ralph Blodgett
Professor of Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Elmo Jackson
Professor of Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ralph Kimbrough
Professor of Education

This dissertation was submitted to the Department of Management in the College of Business Administration and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1972

_____

Dean, Graduate School

University of Florida
1853